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A Research Plan to Study Emissions from Small Internal Combustion Engines

Systems Research and Development Corp.
Resesarch Triangle Park, NC

Prepared for

Industrial Environmental Research Lab.
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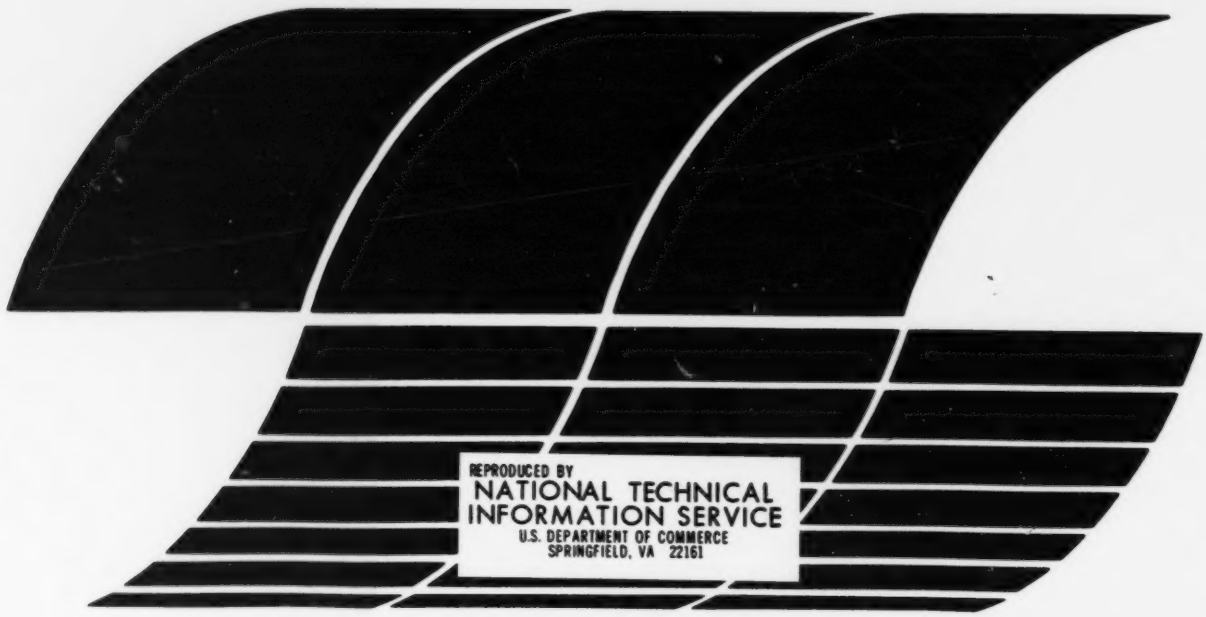

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16. ABSTRACT The report examines some of the requirements for investigating the environmental status of small internal combustion (IC) engines. These engines range in size from 1.5 to 15 hp and power a variety of equipment operated by homeowners and industry. With EPA's general growing concern of identifying sources of potentially carcinogenic emissions, a possibility exists that these small IC engines are a problem source. Research to characterize emissions from IC engines has largely been limited to critical pollutants, even though the small IC engine is an incomplete combustor. It follows that some carcinogens and other hazardous compounds are probable. The basic requirements addressed in the report include analytical equipment, experimental systems design, and statistical experimental design.

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by

James W. Murrell

Systems Research and Development Corporation
P.O. Box 12221
Research Triangle Park, North Carolina 27709

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EPA Project Officer: John H. Wasser

Industrial Environmental Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, NC 27711

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ABSTRACT

This report examines some of the requirements for investigating environmental status of small internal combustion engines. These engines range in size from 1 1/2 hp to 15 hp and power a variety of equipment by home owners and industrial members.

With the general growing concern in EPA of identifying sources of potentially carcinogenic emissions, there exists a possibility that these small internal combustion engines are a problem source. Research to characterize emissions from this source has largely been limited to critical pollutants, even though the small internal combustion engine is an incomplete combustor. It follows that some carcinogens and other hazardous compounds are probable.

The basic requirements addressed in this report include:

a) analytical equipment

b) experimental systems design

c) statistical experimental design

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SECTION 1

INTRODUCTION

Over the past decade, population and energy consumption by way of the internal combustion engine has increased dramatically. Concomitant with these increases has been a dramatic increase in the nation's air pollution problem. An elevated awareness of the hazardous aspects of emissions from these engines has been developed. Most of the research and the ensuing legislation has been aimed at the gasoline powered automobile, and rightfully so. Recently, diesel engines have been given greater attention because of their ever increasing numbers. However, relatively little attention has been focused on the small internal combustion engines in spite of their wide spread usage. Here "small" is defined as 15 horsepower or less and includes engines used to power equipment such as garden tractors, motor tillers, lawn mowers, chain saws and other recreational, industrial and agricultural equipment. General growing concern to identify sources of potentially carcinogenic emissions, has caused the EPA to explore the possibility that internal combustion engines are a problem source. These engines are incomplete combustors, therefore, there is a high probability that carcinogens and hazardous compounds are emitted.

The purpose of designing a comprehensive research plan is to allow emissions from these small internal combustion engines to be characterized. This characterization will account for the interactive impact of several

factors on determining the acceptability of projected ambient concentrations of various emission compounds. As stated earlier, the primary factors are:

-age of engine

-carburetor setting

-revolutions per minute

-mode (or load)

SECTION 2

INFORMATION SEARCH AND ASSESSMENT

The objective of this task is to find what is known about the environmental aspects of small engines. In performing this task, SRD team members used several approaches. Among these were:

-Review of small engine/engine driven equipment

-Review of literature using EPA on-line search system

-Review of related materials in the libraries of area universities

-Interviews with local distributors

In addition, requests for information pertaining to engine size, type (# of strokes), application, emission data, fuel-air mixtures, life expectancy, duty cycle, sales and usage patterns were made from nine major small engine manufacturers.

This task effort confirmed our suspicion of the paucity of information related to distribution, emission characteristics and the health/ecological effects of these small engines. One dramatic indictment of this situation was found in an EPA document containing quantitative information for eighty source categories. These categories were selected by EPA as those common to many areas of the United States and would potentially benefit most from application of control devices. The source categories are classified into eleven major areas with internal combustion being considered a major area. The internal combustion engine category consisted of one sub-category, diesel and dual fuel engines. Not only were small internal combustion engines

omitted, data for the one sub-category was too sketchy for the category to be developed. The internal combustion category is the only category of the twelve where there exists an information void. The remainder of this section will explore the potential impact of some of these emissions.

2.1 HEALTH

Among the more prominent suspected emission are:

-hydrocarcons

-carbon monoxide

-oxides of nitrogen

-particulates

Some detrimental health effects of these compounds are well known. Unburned hydrocarbons have an objectionable odor, contribute to photochemical smog and are possibly carcinogenic. Hydrocarbons may also show up as particulate matter. Studies have shown that high molecular weight hydrocarbons have been carcinogenic in animals.

The toxicity of carbon monoxide has been well documented. It occurs because blood hemoglobin has a higher affinity for carbon monoxide than for oxygen. After approximately one hour of exposure to carbon monoxide at 600 ppm, humans go into a coma. Death usually occurs after one hour of exposure at 800 ppm. There is epidemiological data suggesting increasing incidence of mortality from myocardial infarction after continual average weekly exposure to carbon monoxide concentrations of 8 to 14 ppm.

Oxides of nitrogen have a tendency to combine with lung moisture to form dilute nitric acid. This may cause respiratory problems over extended periods of time. Oxides of nitrogen are also known to settle on blood hemoglobin. Oxides of nitrogen may be regarded as respiratory pollutants. One of the major groups of respiratory pollutants is that of pulmonary

irritants. Many respiratory irritants contribute to the development of cancer. By interfering with ciliary activity and retarding the flow of mucous in the bronchi, they enhance retention of carcinogenic particles in the lungs, and in this way, encourage tumor formation.

2.2 NOISE

The past twenty years are characterized by the increased concern and activity of citizens in environmental issues. Noise pollution is an issue with which both individual citizens and community and environmental organizations have expressed discontent. Most research in this area of pollution has been placed on the response of the individual to airport noise and has focused primarily on the physical/acoustical dimensions of noise exposure.

It is well known that hearing damage can result from high noise and from overexposure to sounds that are at a lower level than the average lawnmower. Sounds levels are usually measured in decibels. Ordinarily, speech might register 60 decibels and sounds from a low flying aircraft may register 120 decibels or more. Hearing discomfort begins at about 95 decibels and pain begins at approximately 140. Hearing damage may begin at a much lower level and is a function of exposure.

Most existing technology can adequately monitor the noise pollution resulting from different classes of small engines.

The most cost effective study for examining the impact of hearing loss due to small engines is a retrospective study. This study would identify a population of individuals who have known time of exposure to sounds from certain types of small engines (professional lumberjacks, etc). These individuals would be compared to a "control" group while controlling for potential confounding variables.

2.3 ESTIMATING NATIONAL HEALTH EFFECT

2.3.1 Overall Effect

The estimation of national health effects requires information on several variables. The variables include:

-Distribution of Engines

-Total population of Engines

-Emission rates

-Usage (exposure) rates

These variables are largely unknown and impossible to determine. It would be impossible to use gasoline sales or engine sales as crude proxy measures. In the former case, fuel sales from small engines can not be distinguished from fuel sales for automotive equipment. On the other hand, engine sales do not reflect engine use nor do they reflect engine life.

One might try estimating some of these variables purely on a deductive basis. This could be done by assuming a reasonable exposure time for the "average" American (i.e., lawn mowing, wood sawing, etc.). An overall effect could then be estimated provided that sufficient data on constituent emissions and their health impact exists. This information would then be combined with user population data to estimate a national health effect. This kind of estimate is crude at best. One study applied such a method in an example aimed at determining the annual exposure time of lawnmower users applying the following assumptions:

1) Each residential lawn cover 10,000 square feet
2) To account for commercial usage (plants, schools, etc.) and sharing among families, each mower cuts two lawn areas
3) Each mower cuts 15-inch swath after correcting for overlap

4) Mower speed is 2 feet/second

5) Grass growing season is 80 days

6) Cutting interval during season is 10 days

It is readily seen that these assumptions, though reasonable, are subject to a large amount of variability.

Ultimately, better estimates can be gotten by performing a stratified random sampling procedure. The scope of the sample should be national and stratification variables could include geographical location, commercial versus non-commercial applications, season and engine characteristics among other potential factors.

2.3.2 The Individual Effect

Section 2.1 examined a few of the known detrimental health effects that particular emissions have on an individual. These effects are expected to be a function of exposure time as well as the concentration of the various components of mass emissions. Once threshold dosages of particular compounds are identified, the "main" effects for that compound may be estimated by appropriate modifications to the empirical model subsequently described.

For a particular source pollutant from a small engine, one could approximate the dose that an operator receives by

$$D = RA \int_0^T C(t)dt$$

where R = Volumetric lung capacity.

A = The body retention rate.

C(t) = Concentration of emissions as a function time.

Under static conditions C(t) would remain constant so that the dosage could be estimated by

$$D = RAC(t_o)T$$

where $C(t_o)$ is the steady state concentration and T is the length of time that the operation is exposed to the emission.

It should be noted that this model does not account for interactive effects and is useful only as a first level estimate of individual dosage.

SECTION 3

ANALYTICAL EQUIPMENT

Since little is known about small engine emissions, one of the basic objectives of the experiment will be to test these emissions to determine the classes of substances that are known or suspected to have adverse health and environmental effects. This can best be accomplished with a Level 1 assessment utilizing an EPA-developed phased approach.

3.1 THE PHASED APPROACH

The phased approach, as developed by the Process Measurements Branch (PMB) of the Environmental Protection Agency, required three separate levels of sampling and analytical effort. The first level, Level 1, utilized quantitative sampling and analysis procedures that yield final analytical results accurate to within a factor of 3 of the samples. Level 1 is designed to (a) provide preliminary environmental assessment data, (b) identify problem areas, and (c) formulate the data needed for the prioritization of energy and industrial processes, streams within a process, components within a process, components within a stream, and classes of materials for further consideration in the overall assessment. The second sampling and analysis effort, Level 2, is directed by Level 1 results and is designed to provide additional information that will confirm and expand the information gathered in Level 1. This information will be used to define control technology needs, and may, in some cases, give the probable or exact cause of a given problem. The third phase, Level 3, involves monitoring the specific problems

identified in Level 2 to provide information for control device design and development. For example, if a Level 1 test indicated that polycylic organic material (POM) might be present in significant amounts and also gave a positive mutagenicity test, Level 2 sampling and analysis would be designed to determine the exact quantities of organic constituents, the percentage of POM, and the identity of as many specific POM compounds present as is economically possible. In addition, using the Level 1 data and any available Level 2 results, the sample would be retested for cytotoxicity and mutagenicity in order to confirm and expand the total bioassay information. A test for carcinogenicity would also be run if the results of these test were positive.[16]

The phased approach offers potential benefits in terms of the quality of information that is obtained for a given level of effort and in terms of the costs per unit of information. This approach has been investigated and compared to the more traditional approaches and has been found to offer the possibility of substantial savings in both time and funds required for assessment.

3.1.1 Level 1 in a Phased Approach

The Level 1 sampling and analysis program is designed to produce a comprehensive survey of emissions from any industry or energy-generating facility that might be of environmental consequence. This survey shows, within broad general limits, the absence or presence, the approximate concentrations, and the emission rates of inorganic elements, selected anions, and classes of organic compounds in gaseous, liquid, and solid samples. Any particulate matter suspended in the effluent gases is analyzed separately for chemical composition, for size, and for other physical parameters that can be determined by microscopic examination. Selective

biotesting is performed on samples to obtain information indicative of the possible human health and ecological effects of the material. If it can be proven that equivalent Level 1 data exist for all streams of interest, then a Level 1 effort need not be conducted. If only partial data exists, then a complete complement of Level 1 tests must be performed on all streams.[16]

The area of analytical equipment is one of rapidly developing technology. It is important to know what equipment is available and at what cost. It is important that analytical equipment used during Level 1 assessment provide a good approximation to the true levels of the compounds being sampled. It is expected that IERL/RTP or the contractor who actually performs the experiment has analytical equipment which is suitable for Level 1 assessment. One of the tasks of the contract under which this report was written was to review and compile some of the more cost-effective analytical equipment. Table 1 depicts the elements of a taxonomy of desirable information characteristics for selecting some of this equipment assuming that no purchases have yet been made. Appendix B contains a representative compilation of some of this equipment.

Taxonomic Dimension	Elements
Sampling	Method
	Volume
	Maximum Temperature Input
	Collection Efficiency
Performance	Accuracy
	Reproducibility
	Linearity
	Noise
	Lag Time
	Retention Time
	Fall Time
	Zero Time
	Span Drift
Operation	Ambient Temperature Range
	Temperature Compensation
	Relative Humidity Range
	Procedure
	Unattended Period
	Maintenance
Requirements	Power
	Weight
	Dimensions
Features	Output
	Training for Operation
	Cost

Table 1. Information gathering form for analytical Equipment.

SECTION 4

EXPERIMENTAL SYSTEM DESIGN

In selecting an experimental system, sampling should be designed to ensure that the emissions obtained are representative of those encountered under normal operating conditions. This task is nearly impossible for small internal combustion engines. Large variability among usage patterns and conditions account for this difficulty. Some of these high variability variables include exposure time, proximity of operator to engine and meteorological conditions. These factors need not be a major concern during initial assessment since their impact may be evaluated by modeling. The primary concern during initial assessment is obtaining sufficient amounts of the various pollutants to adequately characterize the stream. This requires making meaningful measurements. The following list of general criteria should be considered when setting up the experimental system:

A. The nature of the emissions should be classified according to whether they are gases, liquids, particles, or some combination of the three.

B. Efforts should be made to ensure that the emission can be measured separately from other sources of emission.

C. Procedures should be implemented to ensure that sampling does not significantly alter the process.

D. Possible reactive effects between different emissions should be considered.

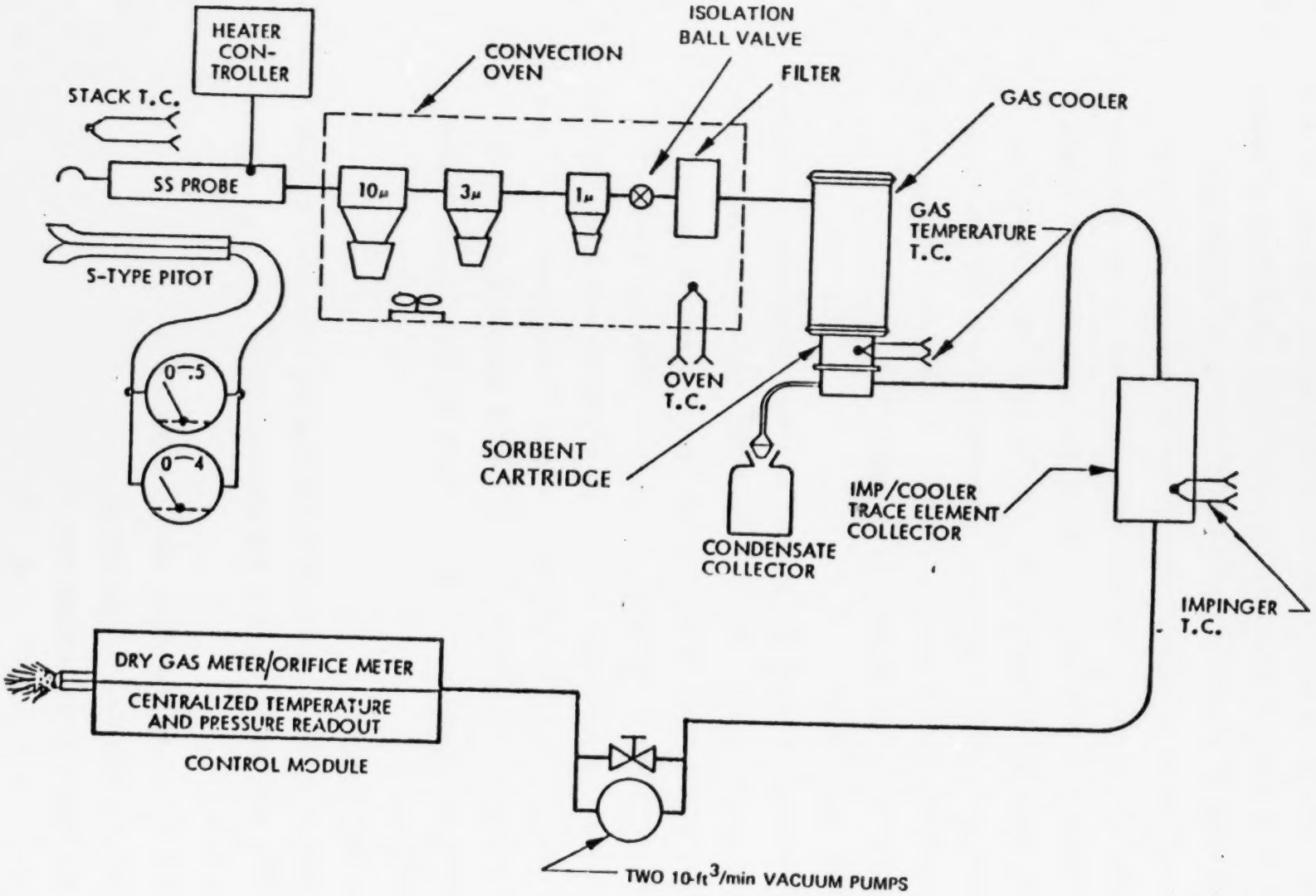
E. Transport air should be controlled so that emission concentration is maintained at a measurable level.

4.1 SAMPLE ACQUISITION

Stationary source particulate matter sampling and analysis have been restricted to streams of high mass loading until recently, because the flow rates through sampling equipment had not been high enough to collect an adequate amoung of material in a reasonable length of time.

Because of this restriction, the development and application of control technology, which requires effluent information on four particulate size ranges, has been hampered. It has also limited health effects studies, which require information on the distribution and composition of respirable and nonrespirable particulate size classes, the presence of volatile organic compounds, and the presence of trace elements to be complete. To correct this situation, EPA(IERL-RTP) has developed and specified the use of the Source Assessment Sampling System (SASS)* for the collection of particulate samples and volatile matter from ducted emissions (Figure 1).

The SASS train consists of a stainless steel probe that connects to three cyclones and a filter in an oven module, a gas treatment section, and an impinger series. Size fractionation is accomplished in the cyclone portion of the SASS train, which incorporates the three cyclones in series to provide large collection capacities for particulate matter nominally size-classified into three ranges: (a) >10 μm, (b) 3 μm to 10 μm, and (c) 1 μm to 3 μm . By means of a standard 142-mm filter, a fourth cut, >1 μm, is also obtained. The gas treatment system follows the oven unit and is composed of four primary components: the gas cooler, the sorbent trap, the aqueous condensate collector, and a temperature controller. Volatile organic



"Figure 1. Source Assessment Sampling Train Schematic."

material is collected in a cartridge or "trap" containing a sorbent, which is designated to be XAD-2, a microreticular resin with the capability of absorbing a broad range of organic species. Volatile inorganic elements are collected in a series of impingers that follow the condenser and sorbent system. The last impinger in the series contains silica gel for moisture removal. Trapping of some inorganic species also may occur in the sorbent module. The pumping capacity is supplied by two 10-ft^3/min, high-volume vacuum pumps, while required pressure, temperature, power, and flow conditions are regulated through a main controller. At least 60 A of power at 110 V is needed for operating the sampling equipment.[16]

4.2 SAMPLING SYSTEM DESIGN

The Quasi-stack method is recommended as a means of ducting total engine emissions to the SASS train. The Quasi-stack Measurement System consists of an enclosure to capture the emission at the source, an exhaust duct or stack in which the emissions are measured, and a blower or fan that directs the emissions through the measurement duct. This method has been widely used for measuring industrial sources of fugitive emissions. The methods can be used with small engine emissions since the basic methodological requirement is that emissions are isolable and capable of being enclosed. Figure 2 shows a typical system.

4.2.1 Hood Requirements

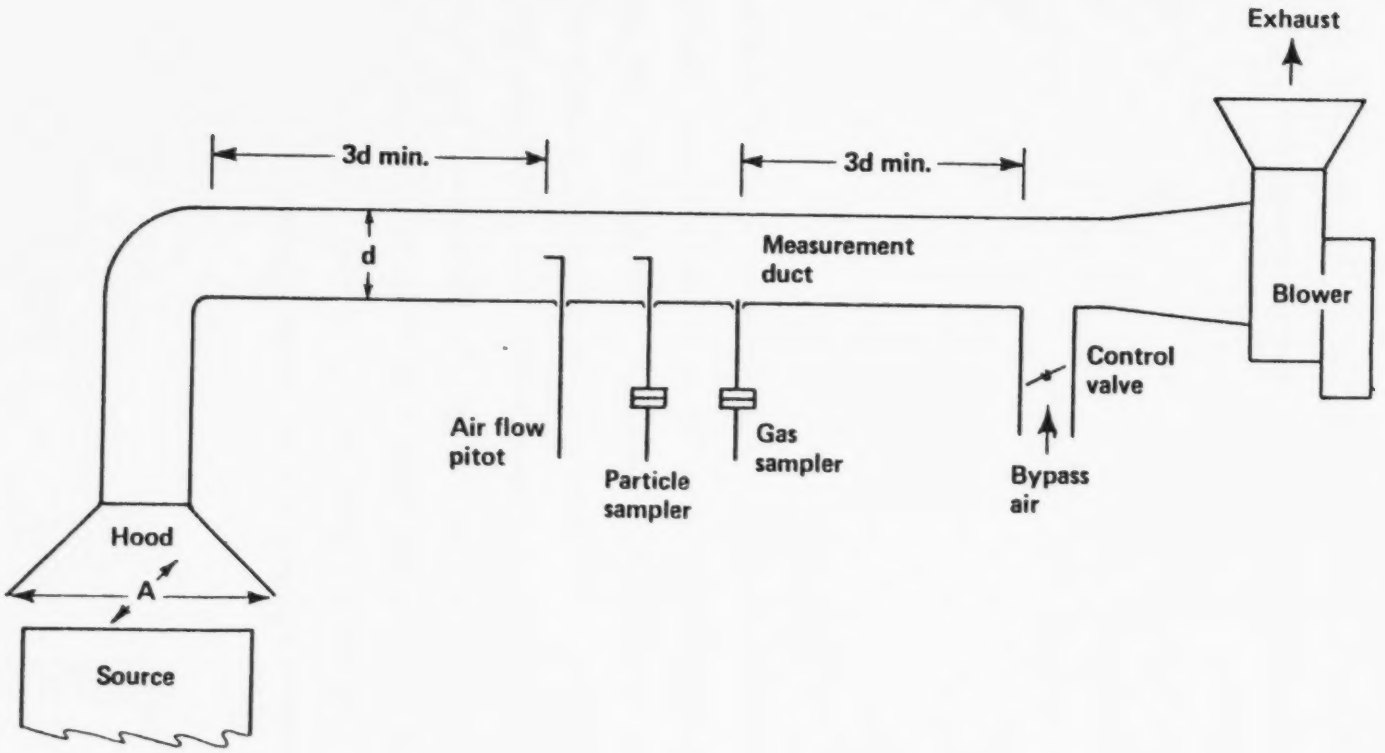
Care must be taken to provide sufficient capture velocity at the hood opening. This area may be computed from the relationship.

$$Q = VA,$$

where Q = air volume flow rate, cubic feet per minute

V = air velocity, feet per minute

A = hood face area, square feet (Figure 2)



"Figure 2. Typical Survey Sampling System."

In order to effectively measure the velocity, temperature and pressure of the flowing stream to determine the total flow rate and to provide the most efficient sample flows, flow in the measurement duct should be in the turbulent range with a Reynold's number of 2×10^5 for a typical smoothwalled duct. The Reynolds number for air is roughly calculated as

$$Re = 110\ dV$$

where Re = Reynolds number, dimensionless

d = duct diameter, feet

V = air velocity, feet per minute

Since $V = Q/A$

and $A = \pi d^2/4$

by substitution, $Re = 140(Q/d)$

and $d = \frac{140}{Re} = \frac{140}{2 \times 10^5} = 0.0007Q$

The blower of fan used to provide the required air flow rate should, in general, be selected to provide about twice the calculated rate to allow for adjustments for inaccuracies in estimates or assumptions. The actual flow rate may be controlled by providing a variable bypass air duct downstream of the measurement duct. Actual system layouts will, of course, be governed by space requirements at the source site. The minimum straight duct runs of 3 duct diameters upstream and downstream of the measurement and sampling ports must be provided to ensure that the sampled flow reaches and remains in fully developed turbulent flow with a uniform velocity profile.

SECTION 5

STATISTICAL EXPERIMENTAL DESIGN

In evaluating the results of any experiment, the inferences that can be made are dependent upon the nature of the data. It is quite possible to sustain tremendous experimental costs while obtaining data from which no inferences can be made. Quite often researchers are forced to choose among several methodological alternatives. When using a factorial experiment, a full factorial design is often the methodological choice. In the case of an experimental design for small engine emissions, one has four factors to consider. Given the proposed level of these factors, a full factorial model would require the total number of runs to be:

3 (Carburetor settings) x 3 (Models) x 2 (RPM) x 2 (Age) x 3 (Engines) =

108 Test runs

This number of runs is obviously costly and unreasonable. The following sections will present alternate designs based on the following recommendations:

A) Initial attention should be given to 3 to 4 horsepower four cycle engines since they represent the most popular size in use.

B) Minimize the number of runs to be performed on the more expensive classes of emissions such as particulate phase polynuclear aromatic (PNA) and vapor phase PNA.

C) Perform replicate runs under "typical conditions" for the class of emissions that are relatively inexpensive to perform.

Two plausible models will be present for each class of emissions. One model utilizes the split-plot design and is a true "experimental design." The second model utilizes a linear model using weighted least squares.

5.1 THE SPLIT-PLOT DESIGN

The split-plot design can be used to obtain information about measures of emissions while reducing the number of runs by the incorporation of combinations of two factors. These factors are divided into "whole plots" and "subplots." These two factors may be depicted as Factor One ("whole plot" or block effects) and Factor Two ("subplot" or treatment effects) which contain I levels and J levels respectively. An important point here is that both factors may actually be made up of a combination of other factors (i.e., $I = I_a\ I_b$). As an example, using the factors in the small engine experiment, Factor One may consist of $I = I_a\ I_b = 6$ combinations where $I_a = 3$ (levels of carburetion settings) and $I_b = 2$ (levels of engine age). In this case, Factor One makes up the whole plot design. In this example, carburetor settings may be randomized among engines of different age. Factor two, the subplot factor would be divided similarly with $J = J_a\ J_b = 6$ being determined by 3 levels of mode randomized over two levels of RPM. Assuming no significant interaction between age and the other factors, the blocks defined by mode and RPM form a (Table 2) 2 x 3 factorial. The combination of Factor One and Factor Two then give rise to the 36 treatment combinations of emissions depicted in Table 3. The configuration assumes that tests will be conducted using six engines.

5.1.1 Analysis Model

Let $$Y_{ijklm} = \mu + \delta_i + \emptyset_j + E_k + \gamma_l + (\emptyset E)_{jk} + (\emptyset\gamma)_{jl} + (E\gamma)_{kl} + (\emptyset E\gamma)_{ijk} + E_{ijkl} \qquad \text{(Model 1)}$$

TABLE 2

Subplot Formulation as a 2 × 3 Factorial

		MODE		
		100%	50%	0%
RPM	2600	A	C	E
	3600	B	D	F

TABLE 3

Emission of SIC Engines by Block (Mode × RPM) and Treatment (CS × Age)

Factor 1 / Factor 2	MR 1	MR 2	FR 3	FR 4	F6 5	F6 6
Mode: 100% RPM: 2600	E_{A1}	E_{A2}	E_{A3}	E_{A4}	E_{A5}	E_{A6}
Mode: 100% RPM: 3600	E_{B1}	E_{B2}	E_{B3}	E_{B4}	E_{B5}	E_{B6}
Mode: 50% RPM: 2600	E_{C1}	E_{C2}	E_{C3}	E_{C4}	E_{C5}	E_{C6}
Mode: 50% RPM: 3600	E_{D1}	E_{D2}	E_{D3}	E_{D4}	E_{D5}	E_{D6}
Mode: 0% RPM: 2600	E^{*}_{E1}	E^{*}_{E2}	E^{*}_{E3}	E^{*}_{E4}	E^{*}_{E5}	E^{*}_{E6}
Mode: 0% RPM: 3600	E^{*}_{F1}	E^{*}_{F2}	E^{*}_{F3}	E^{*}_{F4}	E^{*}_{F5}	E^{*}_{F6}

NOTES:

(1) E_{ij} where $i = A, B, C, D, E, F$ and $j = 1, 2, 3, 4, 5, 6$ are the mean emissions for cell ij.

(2) Cells containing $\star$ are quite atypical and would be omitted for the more expensive runs.

be the M-th observation (replicate at the l-th level of RPM for the k-th level of the mode, j-th level carburetor setting, i-th level of engine age. The parameters of the model are defined as follows:

δ_i = Engine age effect

$\emptyset_j$ = Carburetor setting effect

E_k = Mode effect

γ_l = RPM effect

$(\emptyset E)_{jk}$ = Carburetor setting - mode interaction

$(\emptyset\gamma)_{jl}$ = Carburetor setting - RPM interaction

$(E\gamma)$ = Mode - RPM interaction

$(\emptyset E\gamma)_{ijk}$ = Carburetor setting - mode - RPM interaction

This model may be simplified when considering only the whole plot effect and the subplot effects. The model then becomes;

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + B_{ik} + E_{ijkl} \quad \text{(Model 2)}$$

which represents the l-th subplot at the j-th level of Factor Two (β_j) within the k-th block (whole plot) of the i-th level of Factor One (α_i). It is important to note that Factor Two is a combination of two factors (i.e., according to some specified randomized design scheme. Here it is assumed that treatment effect (Factor Two) are fixed and block effects (Factor One) are random. The estimates obtained are:

$$E[Y_{ijkl}] = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij}$$

$$V[Y_{ijkl}] = \sigma_b^2 + \sigma_E^2$$

$$E[B_{ik}] = 0$$

$$V[B_{ik}] = 0$$

$$E[E_{ijkl}] = 0$$

$$V[E_{ijkl}] = 0$$

The estimates of the interactive and the fixed effects are obtained by ANOVA procedures. Tables 4 and 5 provide the appropriate ANOVA tables for the two models.

5.2 ALTERNATE EXPERIMENT USING LINEAR MODELS

Tables 6 and 7 depict alternate experiments which may be conducted using six engines for the "inexpensive" runs and four engines for the "expensive" runs respectively. Both of these experiments are examples of "Incomplete Block" designs and are most easily analyzed using a general linear models approach. One important assumption in the use of this model is that the combined effects of the independent variables (factors) are additive. This assumption seems fairly reasonable. Subsequent sections describe the model and some elementary matrix procedures which may be employed in estimation and hypothesis testing.

5.2.1 Notations

The general linear model is defined as:

$$\underset{\sim}{Y} = \underset{\sim}{X}\underset{\sim}{\beta} + \underset{\sim}{e}$$

where X is an nxp matrix of rank p<n, $\underset{\sim}{\beta}$ is a pxq matrix of unknown parameter to be estimate and $\underset{\sim}{e} = \underset{\sim}{e}_1, \underset{\sim}{e}_2 \ldots \underset{\sim}{e}_q$ is an nxq of unobservable random deviations. It is assumed that;

$$E(\underset{\sim}{e}) = \underset{\sim}{0} \text{ and } E(\underset{\sim}{e}_i \underset{\sim}{e}_j) = \begin{cases} 0 \text{ if } i \neq j \\ \underset{\sim}{S} \text{ if } i = j \end{cases}$$

and is the unknown qxq variance-covariance matrix to be estimate based on deviations in emissions by factors within the context of Tables 6 and 7, $\underset{\sim}{X}$ is a matrix of dummy variables representing various factors which may be defined as follows:

Let $$\underset{\sim}{X}_1 = \begin{cases} 1 \text{ if carburetor setting = FR} \\ 0 \text{ otherwise} \end{cases}$$

TABLE 4

ANOVA TABLE FOR MODEL I

SOURCE	DF	EMS
WHOLE PLOT		
Age	1	$\sigma_E^2 + 6\sigma_\beta^2 + 18\sum\delta_i^2$
CS	2	$\sigma_E^2 + 6\sigma_\beta^2 + \frac{12}{2}\sum\phi_j$
Whole plot error	2	$\sigma_E^2 + 6\sigma_\beta^2$
SUBPLOT		
Mode	2	$\sigma_E^2 + \frac{12}{2}\sum\varepsilon_k^2$
RPM	1	$\sigma_E^2 + \frac{18}{1}\sum\gamma^2$
Mode * RPM	2	$\sigma_E^2 + \frac{6}{2}\sum\sum(\varepsilon\gamma)_k^2$
CS * RPM	2	$\sigma_E^2 + \frac{6}{2}\sum\sum(\gamma\phi)_j^2$
Mode * CS	4	$\sigma_E^2 + \frac{4}{4}\sum\sum(\varepsilon\phi)_{jk}^2$
Mode * CS * RPM	4	$\sigma_E^2 + \frac{2}{4}\sum\sum\sum(\phi\varepsilon\gamma)_{jk}^2$
Subplot error		σ_E^2

TABLE 5

ANOVA TABLE FOR MODEL II

SOURCE	DF	EMS
WHOLE PLOT ANALYSIS (Between blocks)	5	
Factor one	2	$\sigma_E^2 + 6\sigma_B^2 + \frac{12\sum\alpha_i^2}{2}$
Whole plot error	3	$\sigma_E^2 + 6\sigma_B^2$
SUBPLOT ANALYSIS	30	
Factor two	5	$\sigma_E^2 + \frac{6\sum\beta_j^2}{5}$
Factor one - Factor two Interaction	10	$\sigma_E^2 + \frac{2\sum\sum(\alpha\beta)ij}{10}$
Subplot error	15	σ_E^2

Where, DF = Degrees of Freedom
EMS = Expected Mean Square

TABLE 6

TEST MATRIX FOR INEXPENSIVE EXPERIMENTS

	age = 0 years											
Test Run	Engine 1			Engine 2			Engine 3			Engine 4	Engine 5	Engine 6
	rpm	Mode	CS	rpm	Mode	CS	rpm	Mode	CS			
1	2600	0	FL	2600	0	MR	2600	0	FR	same test	same test	same test
2	2600	50	FR	2600	50	FL	2600	50	MR	runs as	run as	run as
3	2600	100	MR	2600	100	FR	2600	100	FL	Engine 1	Engine 2	Engine 3
4	3600	0	MR	3600	0	FL	3600	0	FL			
5	3600	0	FR	3600	0	FR	3600	0	MR			
6	3600	50	FL	3600	50	MR	3600	50	FL			
7	3600	50	MR	3600	50	FR	3600	50	FR			
8	3600	100	FL	3600	100	FL	3600	100	MR			
9	3600	100	FR	3600	100	MR	3600	100	FR			

TABLE 7
TEST MATRIX FOR EXPENSIVE EXPERIMENTS

Test Run	age = 0 years						age = 5 years	
	Engine 1			Engine 2			Engine 3	Engine 4
	rpm	Mode (%)	CS	rpm	Mode (%)	CS		
1	2600	50	MR	2600	50	FR	same test	same test
2	2600	100	FR	2600	100	MR	runs as	run as
3	3600	50	FR	3600	50	MR	Engine 1	Engine 2
4	3600	100	MR	3600	100	FR		

$$\underset{\sim}{X}_2 = \begin{cases} 1 & \text{if carburetor setting = MR} \\ 0 & \text{otherwise} \end{cases}$$

$$\underset{\sim}{X}_3 = \begin{cases} 1 & \text{if mode = 50\%} \\ 0 & \text{otherwise} \end{cases}$$

$$\underset{\sim}{X}_4 = \begin{cases} 1 & \text{if mode = 100\%} \\ 0 & \text{otherwise} \end{cases}$$

$$\underset{\sim}{X}_5 = \begin{cases} 1 & \text{if RPM = 3600} \\ 0 & \text{otherwise} \end{cases}$$

$$\underset{\sim}{X}_6 = \begin{cases} 1 & \text{if AGE - 5 years} \\ 0 & \text{otherwise} \end{cases}$$

Thus each cell depicted in Tables 6 and 7 denotes an "observation" of some compound. In a strict sense, the X's represent those combination of factors which resulted in the observation of a compound and a corresponding level Y. Thus, the matrix X will have the form:

$$X = [1, X_1, X_2, X_3, X_4, X_5, X_6]$$

This is a "main effects" model and does not include any terms for interaction. Interaction terms may be created by simply multiplying the row elements of the factors of interest. As an example, an RPM--Age interaction is denoted by $\underset{\sim}{X}_5 \underset{\sim}{X}_6$ and if found by creating a new column whose rows reflect the product of the corresponding rows of $\underset{\sim}{X}_5$ and $\underset{\sim}{X}_6$.

5.2.2 Estimation of Parameters

The unknown parameters $\underset{\sim}{\beta}$ and e are estimated by the following matrix relationships:

$$\hat{\underset{\sim}{\beta}} = (\underset{\sim}{X}'\underset{\sim}{X})^{-1}\underset{\sim}{X}'Y$$

$$\underset{\sim}{S} = \underset{\sim}{Y}'[\underset{\sim}{I} - X(\underset{\sim}{X}'\underset{\sim}{X})^{-1}\underset{\sim}{X}']\underset{\sim}{Y}/(n-p)$$

Let $\underset{\sim}{C}$ be a given axp matrix of rank $a \leq p$ and let $\underset{\sim}{\mu}$ be a given axb matrix of rank $b \leq q$. These matrices can be used to estimate linear functions of "regression" coefficients. Hypothesis testing proceeds by testing the linear combinations:

$$H_o: \underset{\sim\sim}{C\beta u} = \underset{\sim}{0} \quad \text{vs} \quad H_a: \underset{\sim\sim}{C\beta u} \neq \underset{\sim}{0}$$

Test statistics are then computed on the basis of the bxb hypothesis matrix defined by;

$$\underset{\sim}{S}_H = (\underset{\sim\sim}{C\hat{\beta}u})'[\underset{\sim}{C}(\underset{\sim}{X}'\underset{\sim}{X})^{-1}\underset{\sim}{C}']^{-1}(\underset{\sim\sim}{C\hat{\beta}u})$$

and the error matrix

$$\underset{\sim}{S}_E = \underset{\sim}{u}'\underset{\sim}{V}[\underset{\sim}{I} - \underset{\sim}{X}(\underset{\sim}{X}'\underset{\sim}{X})^{-1}\underset{\sim}{X}']\underset{\sim\sim}{Vu}$$

Most computer programs provide three test criteria based on S_H and S_E: Roy's largest root criterion, with Heck's parameters; the Hotelling-Lawley trace criterion, with its corresponding approximate chi-square; and, the likelihood ratio criterion with its approximate chi-square.

SECTION 6

SUMMARY

This report is written in a manner that will allow for methodological alternatives during the actual implementation. This will allow the implementation to be based on the goal of optimizing the study in terms of desirable criteria. These criteria may vary depending on numerous factors. An example of a highly possible criteria is cost-effectiveness. This criteria may govern the selection of certain analytical equipment. As an example, in instances where there is no appreciable gain in performance, it is always most cost-effective to utilize equipment that is already on hand. For this reason, the report reflects some of the desirable characteristics of certain components of the experimental systems without making formal references to specific manufactures or their line products.

The theme of flexible alternatives is carried over to the statistical design. Two designs are presented. One statistical model is a "classical" experimental design while the other is a linear models approach which readily accommodates multiple replications.

Current small engine population data is sparse. Getting this information for the estimate of national impact should be done by a carefully planned statistical sample.

This report is the end-product of efforts to formulate a basic research strategy to study emissions from small internal combustion engines. This work was performed under EPA Contract No. 68-02-3113.

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APPENDIX A-1
ANNOTATED BIBLIOGRAPHY

SOURCE:

A Study of Emissions From 1966 - 1972 Light Duty Vehicles in Los Angeles and St. Louis, Prepared by Automotive Environmental Systems, Inc., August 1973

DESCRIPTION:

A comprehensive study of exhaust and evaporative emissions from light duty vehicles was performed in Los Angeles, California; and St. Louis, Missouri, to determine the contribution to atmospheric pollution by 1966 through 1972 model year vehicles. This study was part of a total effort to measure the emissions from light duty vehicles in six cities. Automotive Environmental Systems, Inc., under contract to the EPA, performed exhaust emissions tests on 170 vehicles in Los Angeles, California; and St. Louis, Missouri, and evaporative emissions tests on twenty 1972 model year vehicles in Los Angeles, California.

MEASUREMENT:

The emissions tests determined the levels of hydrocarbons, carbon monoxide, carbon dioxide and oxides of nitrogen exhaust emissions as well as hydrocarbon evaporative emissions.

SOURCE:

Dorsey, James A. et al, Environmental Assessment Sampling and Analysis: Phased Approach and Techniques for Level 1, June 1977.

DESCRIPTION:

A sampling and analytical approach has been developed for conducting environmental source assessments of the feed, product, and waste streams associated with industrial and energy processes.

This document presents an overview of: the historical development of the strategy, the concepts employed, the measurement techniques applied, and the costs of program implementation.

Components of an environmental source assessment program:

1. A systematic evaluation of the physical, chemical and biological characteristics of all streams associated with a process;
2. Predictions of the probable effects of those streams on the environment;
3. Prioritization of those streams relative to their individual hazard potential, and
4. Identification of any necessary control technology programs.

Ultimate goals of environmental source assessment:

1. To ensure that the streams from a given processing scheme will be environmentally acceptable, or
2. Ensure that adequate control technology either exists or can be developed.

Information effective strategies:

Two clearly distinct strategies which would satisfy the requirements for

comprehensive information are the direct and phased approaches. In a direct approach, all streams would be carefully sampled and the samples subjected to complete detailed analysis for all detectable components at an overall accuracy of 50 percent. In a phased approach, all streams would first be surveyed using simplified, generalized sampling and analytical methods which would permit their ranking on a priority basis (Level 1) i.e., very hazardous streams would be distinguished from those less hazardous or relatively innocuous in nature.

Detailed sampling analysis (Level 2) would then be applied first to streams ranked in the highest priority by the Level 1 survey, and other streams would be addressed in descending order to potential hazard. Another phase, initiated after consideration of Level 1 and 2 results, would involve the continuous monitoring of "key" indicator materials to evaluate long-term process variability (Level 3).

Cost-effectiveness--Direct and Phase Approaches:

Studies were conducted by the staff of the process measurements branch of EPA's IERL-RTP with the objective of comparing the costs of direct and phased (eliminating low priority streams) sampling and analysis approach. In both cases studied, the phased approach was found to be more cost-effective than the direct approach.

Sampling Programs in a Phased Approach:

The most cost-effective approach clearly is one in which detailed sampling is performed only on those streams demonstrated to be potentially hazardous. It is not sound practice to attempt to define a detailed sampling program until:

1. The general characteristics of the stream in question have been evaluated.
2. The nature of any unfavorable sampling system/sample interactions

has been considered (e.g., chemical reaction, volatility loss).

MEASUREMENT:

Level (1) Analysis

Level (1) sampling provides a single set of samples acquired to represent the average composition of each stream. This sample set is separated into solid, liquid, and gas-phase components. Each fraction is evaluated with survey techniques which define its basic physical, chemical, biological characteristics.

In Level (1), the analytical techniques and instrumentation have been kept as simple as possible to provide an effective level of information at minimum cost. Physical analysis of solid samples is incorporated into Level (1) because the size and shape of the particles have a major effect on their behavior in process streams, control equipment, atmospheric dispersion, and the respiratory system. Some materials have characteristic physical forms which can aid in their identification.

Chemical analyses to determine the types of substances present are incorporated to provide information for predicting: control approaches, atmospherical dispersion/transformation, and potential toxicity of the stream. Biological assay techniques are incorporated as a measure of the potential toxicity.

Level (2) Analysis

Level (2) analyses must positively identify the materials in sources which have already been defined as causing adverse environmental effects. These are the most critical of all three levels. Each sample in Level (2) assessing will require the analyst to select appropriate techniques based on the

information developed in Level (1) and the information requirements of the assessments.

Level (3) Analysis

The analytical procedures for Level (3) are specified to the stream components being monitored, and it is not possible to define the exact form they may take. These analyses are oriented toward the time variation in the concentrations of key indicator materials. Both manual and instrumental techniques may be used, providing they can be implemented at the process site. At Level (3), continuous monitors for selected pollutants should be incorporated in the analysis program as an aid in interpreting the data acquired through manual techniques.

METHODOLOGY:

Level (1) Methodology and Components

Level (1), the principal subject of this section, is structured to produce a cost-effective information base for prioritization of streams and for planning any subsequent programs. It seeks to provide input data to support evaluation of the following questions:

-- Do streams leaving the processing unit have a finite probability of exceeding existing or future air, water, or solid waste standards or criteria?

-- Do any of the streams leaving the processing unit contain any classes of substances that are known or suspected to have adverse environmental effects?

-- Into what general categories (classes) do these adverse substances fall?

-- What are the most probable sources of these substances?

-- Based on the adverse effects and mass output rates, what is the priority ranking of streams?

-- For streams exhibiting potential environmental effects, what is the basic direction that control strategies are likely to follow?

The Level (1) measurement program provides information on the physical characteristics, chemical composition, and biological effects of a given stream.

SOURCE:

Duke, K. M., et al, IERL-RTP Procedures Manual: Level 1 Environmental Assessment Biological Tests for Pilot Studies, April 1977.

DESCRIPTION:

This manual focuses on the Level 1 sampling and bioassy effort of the three phased approach to performing an environmental source assessment -- the testing of feed and waste streams associated with industrial processes in order to define control technology need. Each phase involves distinctly different sampling and analytical activities.

The three phased sampling and analytical strategy was developed to focus available resources (both manpower and dollars) on emissions which have a high potential for causing measurable health or ecological effects, and to provide chemical and biological information on all sources of industrial emissions.

The Level 1 sampling and analysis goal is to identify the pollution potential of a source. Level 1 has at its most important function the selection, in order of relative toxicity, of specific streams and components for the Level 2 effort.

The manual presents the strategy of the phased approach. It also presents the basic sampling procedures and the Level 1 protocol for the biological tests used to analyze the samples. It briefly discusses possible bioassay procedures for Level 2 and 3.

SOURCE:

Jay, Frederic C., Monitoring Instrumentation for the Measurement of Sulfur Dioxide in Stationary Source Emissions, February 1973.

DESCRIPTION:

Substances: The SO_2 stack gas monitoring instrumentation is comprised of a sampling system, including any necessary sample conditioning equipment, and a measuring system including an analyzer and recorder. The system is to be used to continuously determine quantitatively the concentration of SO_2 gas in exit gas from stationary power plants using fossil fuels.

Experiments: Five nondispersive infrared (NIDR) SO_2 monitors were studied. The units considered were: 1) Leeds and Northrop - IR gas analyzer, 2) Bendix Unor, 3) Intertech Uras, 4) Beckman Model 315A, 5) MSA - Lira Model 300. All units used as their principle means of detecting SO_2 the selective absorption of infrared radiation by SO_2 molecules, and consisted of an IR source, a chopper, a sample chamber, a reference chamber, and a detector unit.

Conclusions: All the instruments studies were only conditionally suitable for use as continuous monitors since all suffered interference from particulate matter, water vapor and vibration.

It was concluded that the proper ranking of the instruments could only be done after the instruments had been subjected to laboratory tests to measure their performance.

Experiments: Commercially available SO_2 analyzers based on the use of electrochemical principles were evaluated for use in continuous monitoring SO_2 in stack gases. The evaluation

included a review of: basic electrochemical principles involved, theoretical and practical limitations, possible interference from other stack gas constituents, operating procedures, maintainability, and physical construction.

The instruments were of three types: conductimetric, coulometric, and "fuel cell."

Conclusions: Conductimetric instruments measure the change in conductivity of a solution resulting from the addition of SO_2. Instuments found to be capable of monitoring SO_2 in stack gases were: Mikrogas - MSK - SO_2 - El by Calibrated Instruments Model 70 Stack Monitoring System by Scientific Industries.

Coulometric instruments are based on the principle of coulometric titration where electrogenerated halogen (bromine or iodine) serves as the titrant. Instruments recommended for possible use in stack-gas monitoring are: Model 286/ or 400 by ITT Barton, Diffusion Stack Monitor Model 906A by Beckman Instruments.

The "fuel cell" - type instruments are based on a completely sealed sensor functioning as an electrochemical transducer. Some of the drawbacks of this type of instrument are: 1) Membrane is not highly specific to SO_2 (NO_2 is a major interfering species); and 2) Membrane surface must be kept free of condensate and particulates. Only the basis of data from the field test program, the following equipment is recommended for use in SO_2 control technology development programs:

a. Calibrated Instruments Co. Model MSK-SO_2-El

conductometric SO_2 analyzer installed according to schematic 521-S1/2.

b. DuPont model 460 untraviolet SO_2 analyzer when calibration gas standards are used instead of the optical calibration filter for calibration purposes.

c. Intertech model URAS-2 non-dispersive infrared SO_2 analyzer when used with model 7651 probe and filter, model 7865 auto zero and calibration units. The CMR 5869 unit shall be set at 8 hour intervals.

These recommendations are made on the basis of:

a. Proven reliability and performance.

b. The availability of the unit as a complete system.

The conclusions from interpretation of the data concerning the definition of the state-of-the-art in SO_2 monitoring are:

a. There is equipment available which is adequate for the monitoring purpose required by the New Source Performance Standards of December 23, 1971.

b. The equipment which does operate properly is that which is available as a complete system consisting of probe, particulate filtration, sample conditioning and analyzer equipment.

c. No particular measurement technique is superior to all others.

d. A major operational problem encountered with most of the units was the variance of instability of the "zero" setting.

SOURCE:

Ballant, R. R. et al, Characterization of Sorbent Resins for use in Environmental Sampling, March 1978.

DESCRIPTION:

This technical report has information pertaining to the use of chromatographic techniques to characterize resins which are used to trap vapors in environmental sampling schemes. Two chromatographic techniques are described, frontal and elution analysis.

Three diverse adsorbate groups, consisting of eight distinct chemical classes, were studied as potential pollutants.

Sorbent modules are frequently employed as one of a number of collection devices or stages in a multi-purpose sampling device, such as the EPA-SASS train. The SASS train sorbent trap is primarily designed to capture organic species that have sufficient volatility to pass through particulate filters upstream from the sorbent bed.

One of the more common methods of characterizing absorbents is the use of gas chromatography. Characteristics data may be obtained by both elution analysis methods. The elution method introduced a small quantity of sorbate to the sorbent in a short time. In the frontal method the sorbent is continuously challenged with a steady state concentration sorbate.

The data presented in this report support the use of chromatographic elution data to characterize breakthrough and sorption capacity of sorbent cartridges containing synthetic resins.

SOURCE:

Hamersma, S. L., et al, IERL-RTP, Procedures Manual: Level 1 Environmental Assessment, June 1976.

DESCRIPTION:

This manual describes a set of sampling and analytical procedures compatible with the information requirements of a comprehensive Level 1 environmental assessment.

The phased sampling and analytical strategy was developed to focus available resources (manpower and dollars) on emissions which have a high potential for causing measurable or ecological effects, and to provide comprehensive chemical and biological information on all sources of industrial emissions.

The phased approach requires three separate levels of sampling and analytical effort. The first level utilized quantitative sampling and analysis procedures accurate within a factor of 2 to 3 and: 1) provides preliminary environmental assessment data, 2) identifies problem areas, and 3) formulates the data needed for the prioritization of energy and industrial processes, streams within a process, components within a stream, and classes of materials for further consideration in the overall assessment.

The manual is divided into two major sections: sampling procedures and analytical procedures. The sampling section is divided into five chapters: fugitive emissions, gases, aerosols, liquids, (including slurries), and solids. The analytical section is divided into three chapters: inorganic, organic and bioassays.

SOURCE:

Hare, Charles T., Springer, Karl J., Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines: Part 4 Small Air-Cooled Spark Ignition Utility Engines, APTD-1493, May 1972.

DESCRIPTION:

This document is Part 4 of the Final Report on Exhaust Emissions of Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Exhaust emissions from five gasoline-fueled, air-cooled utility engines were measured using two types of steady-state procedures, measurements were taken during transient operation.

The study includes test data, documentation, and discussion on detailed emissions characterization of five engines (one 2-strokes and four 4-stroke), as well as estimated emission factors and national emissions impact.

MEASUREMENT:

The exhaust products measured during the emissions tests included:

1. Total hydrocarbons by FIA
2. Hydrocarbons, CO, CO_2 and NO by NDIR
3. O_2 by electrochemical analysis
4. Light hydrocarbons by gas chromatograph
5. Total aliphatic aldehydes (RCHO) and formaldehyde (HCHO) by the MBTH and chromotropic acid method, respectively.

SOURCE:

Hare, Charles T., Springer, Karl J., Exhaust from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines: Part 7-Snowmobiles, April 1974.

DESCRIPTION:

This is part 7 of the Final Report on Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines.

Exhaust emissions from four snowmobile engines were measured using steady-state "mapping" procedures, employing 29 combinations of speed and load for each engine.

The engines tested were an Artic 440, a Polaris 335, a Rotax 248, and an OMC 528 rotary. The first three engines listed are all 2-stroke vertical twins with blower cooling, and the last engine is a blower-(and charge-) cooled rotary combustion (Wankel) engine.

MEASUREMENT:

The gaseous exhaust constituents measured on a continuous basis during all the test modes included:

1. Total hydrocarbons by FIA:
2. CO, CO_2, NO, and HC by NDIR;
3. NO and NO_x by chemiluminescence;
4. O_2 by electrochemical analysis

SOURCE:

Hare, Charles T., Springer, Karl J. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines: Part 5 Heavy-Duty Farm, Construction, and Industrial Engines, October 1973.

DESCRIPTION:

This report is Part 5 of the Final Report on Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. The engine categories covered in this report are heavy-duty gasoline and diesel engines used in farm, construction, and industrial applications. Exhaust emissions from twelve engines were measured, including eight diesels and four gasoline engines.

The program of research on which this report is based was initiated by the EPA to (1) characterize emissions from a broad range of internal combustion engines in order to accurately set priorities for future control as required, and (2) aid in the development of more inclusive national and regional air pollution inventories.

MEASUREMENT:

The emissions to be measured for all the engines included:

1. Hydrocarbons by FIA;
2. CO, CO_2 and NO by NDIR;
3. NO and NO_x by chemiluminescence;
4. O_2 by electrochemical analysis;
5. Light hydrocarbons by gas chromatograph;
6. Aldehydes by wet chemistry;
7. Particulate by gravimetric analysis. In addition, hydrocarbons were to be measured by NDIR for gasoline engines, and smoke by the PHS full-time smoke-meter for diesel engines.

SOURCE:

Hare, Charles T., Springer, Karl J., Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines: Part 6- Gas Turbine Electric Utility Power Plants.

DESCRIPTION:

This document is Part 6 of the Final Report on Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. In contrast to the other phase of the subject contract, no measurements of emissions from the source under consideration (Gas Turbine Electric Utility Powerplants) were taken as part of the research project. The reasons for this departure were that information on gas turbine emissions available in the literature was deemed sufficient (at least on the major emissions) and that the small test effort possible within the scope of the contract would hardly add anything worthwhile to that body of knowledge.

MEASUREMENT:

Emissions data include, NO, NO_2, and NO_x measured by a variety of techniques; a less substantial amount of CO and hydrocarbon data; either CO_2 or O_2 (occasionally both) for a given test; and scattered information on SO_x particulate, visible smoke, and less important pollutants.

SOURCE:

Hare, Charles T., Springer, Karl J., Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines: Part 3-Motorcycle, March 1973.

DESCRIPTION:

This report is Part 3 of the Final Report on Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Exhaust emissions from seven motorcycles were measured using three separate procedures for each bike. Though motorcycles are currently exempt from Federal emissions regulations, two of the procedures used for testing were based on those specified in federal law for automobiles.

MEASUREMENT:

The first procedure used for the motorcycle tests was the Federal "7-mode" direct sampling procedure (applicable to 1970 and 1971 model year light duty vehicles), modified when necessary. The exhaust components measured for the 7-mode tests included hydrocarbons, CO, CO_2, and NO, all by NDIR.

The Federal "LA-4" bag sampling procedure was also used to test the motorcycles; this procedure was modified as necessary. Currently it specifies measurement of the following:

1. Hydrocarbons by FIA
2. CO and CO_2 by NDIR
3. NO and NO_x by chemiluminescence

The final procedure was a series of steady-state conditions designed to cover the range of operating conditions experienced by each motorcycle. Exhaust products measured during this procedure included:

1. Total hydrocarbons by FIA;
2. Light hydrocarbons by gas chromatograph (2 of the 7 machines only);
3. Hydrocarbons, (2 of the 7 machines only);
4. CO, CO_2, and NO by NDIR;
5. NO and NO_x by chemiluminescence;
6. O_2 by electrochemical analysis;
7. Total aliphatic aldehydes (RCHO) and formaldehyde (HCHO) by the MBTH and chromotropic acid method, respectively;
8. Particulate by an experimental dilution type sampling device;
9. Exhaust smoke (2-stroke machines only) using PHS full-flow smoke meter

SOURCE:

Hare, Charles T., Springer, Karl J., Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines: Part 2-Outboard Motors, APTD-1491, January 1973.

DESCRIPTION:

This report is Part 2 of the Final Report on Exhaust Emissions of Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. The study includes documentation and discussion on characterization of exhaust emissions from four water-cooled 2-stroke outboard motors (Section III and IV), and estimation of emission factors and national impact (Section V).

MEASUREMENT:

Exhaust emissions from four 2-stroke outboard motors were measured.

The components measured were:

1. Total hydrocarbons by FIA
2. CO, CO_2, NO, and hydrocarbons by NDIR
3. NO and NO_x by chemiluminescence
4. O_2 by electrochemical analysis
5. Light hydrocarbons by gas chromatograph
6. Total aliphatic aldehydes and formaldehyde by the MBTH and chromatropic acid methods, respectively.

SOURCE:

Hare, Charles T., Springer, Karl J., Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines: Part 1- Locomotive Diesel Engines and Marine Counter Parts, October 1972.

DESCRIPTION:

This document is Part 1 of the Final Report on Exhaust Emission from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines.

The program of research on which this report is based was initiated by the Environmental Protection Agency to (1) characterize emissions from a broad range of internal combustion engines in order to accurately set priorities for future control, as required, and (2) assist in developing more inclusive national and regional air pollution inventories. This document, which is Part 1 of what is planned to be a seven-part final report, concerns emissions from locomotive diesel engines (and their marine counterparts) and the national impact of these engines.

The primary objectives of the locomotive portion of this project were to collect useful emissions data on three locomotive diesel engines, and to use these data in conjunction with supplementary data on emissions, number of units in service, and annual usage to estimate emission factors and national impact.

MEASUREMENT:

The emissions to be characterized included:

1. Total hydrocarbons;
2. Light hydrocarbons;
3. Aldehydes;
4. CO, CO_2 NO by NDIR and chemiluminescence;

5. NO_x by chemiluminescence;

6. O_2

7. Smoke by a modified PHS opacity meter;

8. Particulate by an experimental dilution-type sampling system

SOURCE:

Kolnsberg, H. J., Technical Manual for the Measurement of Fugitive Emissions: Quasi-Stack Sampling Method for Industrial Fugitive Emissions, May 1976.

DESCRIPTION:

The objective of this manual is to present the fundamental considerations required for the use of the Quasi-Stack sampling method in the measurement of fugitive emissions.

EMISSIONS- Pollutants emitted into the ambient air from an industrial plant or other site generally fall into one of two types. The first type is released into the air through stacks or similar devices designed to direct and control the flow of the emissions, and they may be readily measured by universally-recognized standard sampling techniques. The second type is released into the air without control of flow or direction; these cannot be measured using existing standard techniques.

Categories of Fugitive Emissions

A useful approach toward categorization of fugitive emissions is to group them according to the methods of their measurement. Three basic methods exist--quasi-stack sampling, roof monitor sampling, and upwind-down-wind sampling.

SAMPLING:

QUASI-STACK SAMPLING METHOD

This method has the fugitive emissions captured in a temporarily installed hood or enclosure and vented to an exhaust duct or stack of regular cross-sectional area. The emissions are then measured in the exhaust duct using standard stack sampling or similar well recognized methods.

Sources of fugitive emissions measurable by the quasi-stack method include:

--Material transfer operations

Solids-conveyor belts, loading

Liquids-spray, vapors

--Process leaks

Solids-pressurized ducts

Liquids-pumps, valves

--Evaporation

Cleaning fluids-degreasers, wash tanks

Paint solvent vapors-spray booths, conveyors

--Fabricating operations

Solids-grinding, polishing

Gases-welding, plating

ROOF MONITOR SAMPLING METHOD

This method measures the fugitive emissions entering the ambient air from building or other enclosure openings such as roof monitors, doors, and windows from enclosed sources too numerous or unwieldy to permit the installation of temporary hooding. Sampling generally is limited to a mixture of all uncontrolled emission sources within the enclosure and requires the ability to make low air velocity measurements and mass balances of small quantities of material across the surface of the openings.

UPWIND-DOWNWIND SAMPLING METHOD

This method is used to measure fugitive emissions from sources typically covering large areas that cannot be temporarily hooded and are not enclosed in a structure allowing the use of the roof monitor method.

The upwind-downwind method quantifies emissions from sources such as material handling and storage operations, waste dumps and industrial processes in which

the emissions are spread over large areas or are periodic in nature.

The emissions from such sources are quantified as the difference between the pollutant concentrations measured in the ambient air approaching (upwind) and leaving (downwind) the source site.

MEASUREMENT:

Quasi-Stack Method

Effective use of the quasi-stack method requires that the source of emissions be isolable and that an enclosure can be installed capable of capturing emissions without interference with plant operations.

The quasi-stack method is mainly restricted to a single source and must be limited to two or three small sources that can be enclosed to duct their total emissions to a single sampling point. In some cases, enclosing a portion of a process in order to capture its emissions can alter that portion of the process by changing its temperature profile or affecting flow rates. Emissions may be similarly altered by reaction with components of the ambient air drawn into the sampling ducts.

The quasi-stack method is useful for all types of emissions. One of the reasons for this is it will provide measurable samples in generally short sampling times since it captures essentially all of the emissions.

Roof Monitor Method

The roof monitor method requires that the source of emissions be enclosed in a structure with a limited number of openings to the atmosphere.

This method is usually dependent on or influenced by gravity in the transmission of emissions, and it may not be useful for the measurement of larger particles which may settle within the enclosure being sampled. Emission generation rates must be high enough to provide pollutant concentrations of measurable magnitude

after dilution in the enclosed volume of the structure.

Upwind-Downwind Method

This method is generally used where neither of the other methods would be successful. The method is strongly influenced by meteorological conditions, and requires a wind consistent in direction and velocity throughout the sampling period as well as conditions of temperature, humidity and ground moisture representative of normal ambient conditions.

OTHER CONSIDERATIONS:

Sampling Strategies

Fugitive emissions measurements can be separated into two classes. Survey measurement systems, designed to screen emissions and provide gross measurements at a relatively low level of effort in time and cost. Detailed systems are designed to isolate, identify and quantify constituents with increased accuracy and higher investments in time and cost.

Test Strategies

Approaches that may be taken to successfully complete a testing program using the quasi-stack sampling method are described.

Instrumentation/Equipment/Facilities

A description of the instrumentation arrays to be used to collect the samples and meteorological data identified in the approach description.

A description of the facilities required to operate the measurement program, including work space, electrical power, support from plant personnel, special construction, etc.

Quality Assurance

The test plan should address the development of a quality assurance program. This QA program should be an integral part of the measurement program and be

incorporated as a portion of the test plan either directly or by reference.

Quasi-Stack Sampling Strategies

This method is used to quantify the emissions from a source by capturing the emissions, entrained in the ambient air, in a temporary hood or enclosure built over or around the source and directing the captured stream through a duct of regular cross section for measurement, sampling and analysis using standard stack techniques.

Survey Quasi-Stack Sampling Strategy

A survey measurement system is designed to provide gross measurements of emissions to determine whether any pollutant constituents should be considered for more detailed investigation. A quasi-stack measurement system consists basically of a hood or other enclosure to capture the emissions at the source, an exhaust duct or stack in which the emissions are measured, a fan or blower to direct the emissions through the measurement duct, and the emissions sampling equipment.

SAMPLING EQUIPMENT:

Particulate pollutants may be grossly measured conveniently using any of a large variety of filter impaction devices. Gaseous pollutants may be grab-sampled for laboratory analysis into suitably-sized vessels added to the particulate sampling train or separate sampling ports elsewhere in the measurement duct.

An alternative method for the measurement of particulates and volatile matter is the recently developed source assessment sampling system (SASS) train. The train consists of a stainless steel probe that delivers the sample to an oven module. This device, used in combination w'th a gas-sampling, provides all the information required as the nature and composition of the pollutants in

Sampling Techniques

The primary concern of the sampling design is that sufficient amounts of the various pollutants are collected to provide meaningful measurements.

Information on detailed quasi-stack sampling strategy, sample equipment and design and sampling techniques are described.

Quality Assurance

The basic reason for quality assurance on a measurement program is to insure that the validity of the data collected can be verified.

An Appendix is also furnished in this document. It represents an application of the quasi-stack fugitive emissions measurement system selection and designed criteria to a gray-iron foundry mold pouring operation.

SOURCE:

Lear, C. W., Charged Droplet Scrubber For Fine Particle Control: Laboratory Study, September 1976.

DESCRIPTION:

This document gives results of a feasibility study of the application of charged droplet scrubbing for fine particle control. Results, using the TRW charged droplet scrubber, indicated that the method is feasible and applicable over a wide range of conditions. In the charged droplet scrubber the electrical interaction mechanisms exist in addition to the normal impact and diffusional scrubbing mechanisms. Electrical interaction is strong in the 0.1 to 1.0 micron particulate size range where the normal mechanisms lack effectiveness. Collection efficiencies as high as 80% for 0.1 micron and 90% for 1 micron particles were demonstrated in a three-stage unit. Induced charging or dry charging of particulate by charge transfer from droplets is an effective and major collection mechanism in the fine particulate size range. Large (100 micron) droplets give better performance characteristics than small (10 micron) droplets.

SOURCE:

Shih, C. C., et al, Emissions Assessment of Conventional Stationary Combustion Systems; Volume II. Internal Combustion Sources, February 1979.

DESCRIPTION:

Emission from gas-and oil-fueled gas turbines and reciprocating engines for electricity generation and industrial applications are assessed in this report. The assessment method involved a critical examination of existing emissions data, followed by the conduct of a measurement program to fill data gaps based on a phased sampling and analysis strategy.

MEASUREMENT:

In the first phase of the measurement program, one gas-fueled gas turbine, five distillate-oil fueled gas turbines, and five diesel engines were selected for testing. Evaluation of test results led to the recommendation for additional tests to determine SO_3 and organic emissions from diesel engines which were subsequently conducted at three of the diesel engine sites previously tested.

The results of the emissions assessment indicate that internal combustion sources contribute significantly to the national emissions burden. NO_x, hydrocarbon and CO emissions from internal combustion sources account for approximately 20 percent, 9 percent, and 1 percent of the emissions of these pollutants from all stationary sources. The source severity factor, defined as the ratio of the calculated maximum ground level concentration of the pollutant species to the level at which a potential environmental hazard exists, was used to identify pollutants of environmental concern.

SOURCE:

Smith, E. M., Little, Authur D., Sensitized Fluorescence for the Detection of Polycylic Aromatic Hydrocarbons, September 1978.

DESCRIPTION:

Summary

A fluorescent spot test has been devised for polycyclic aromatic hydrocarbons (PAH) based on the sensitization of the inherent fluorescence of such compounds. The basic procedure involves spotting a filter paper with a small amount of the sample solution, adding napthalene, in solution, to the spot and visually observing the fluorescence under illumination with a simple ultraviolet light source.

This project was initiated to determine whether the phenomenon of fluorescence could be utilized in the analysis of polynuclear aromatic hydrocarbons (PAH) as a class. A major objective was to develop a simple procedure for detection of PAH at much lower levels than current methods based on fluorescence analysis. This procedure requiring only instrumentation readily available to most laboratories, would provide a low cost screening technique to determine whether environmental assessment samples contained levels of PAH such that more detailed analyses should be undertaken.

Suggested Applications

In its present form the sensitized fluorescence spot test is useful for screening environmental assessment samples for the presence of PAH at least as low as 10 ug/L (pg/uL) in solution. The absence of sensitized fluorescence might well indicate that additional analyses for PAH are not necessary; on the other hand, a positive fluorescence test might indicate that GC/MS analyses should be performed to determine the exact nature of the PAH detected.

SOURCE:

Pefley, R. K., Saad, M. A., et al, Study of Decomposed Methanol As A Low Emission Fuel - Final Report, April 30, 1971.

DESCRIPTION:

Studies were conducted to evaluate blends of pure and decomposed methanol ($2H_2$ + CO) as fuels for reducing automotive IC engine air pollution. These investigations included laboratory IC engine tests and analysis, and preliminary design study of possible methanol decomposition chambers with associated engine air-fuel (A/F) ratio controls.

MEASUREMENT:

Steady-state performance and emission tests were made on a variable compression ratio CFR engine operating at 900 RPM. A total of 191 tests were conducted. They included 184 tests with methanol blends and seven comparative gasoline fueled tests. Engine test variables were A/F ratio, percent methanol dissociation, compression ratio (CR), spark advance, and intake manifold temperature.

INSTRUMENTATION:

Instrumentation consisted of apparatus for measuring air and fuel flow rates, engine load, engine emissions and various engine temperatures. Emission instrumentation included CO, CO_2, and NO_x gas analyzers and a gas chromatograph (GC) using a flame ionization detector.

SOURCE:

Wilson, R. R., et al, Guidelines for Particulate Sampling in Gaseous Effluents from Industrial Processes, January 1979.

DESCRIPTION:

This guideline document lists and describes briefly many of the instruments and techniques that are available for measuring the concentration or size distribution of particles suspended in process streams. The standard, or well established, methods are described as well as some experimental methods and prototype instruments.

Descriptions of instruments and procedures for measuring mass concentration, opacity, and particle size distribution are given. Precedures for planning and implementing tests for control device evaluation are also included.

APPENDIX B-1
ANALYTICAL EQUIPMENT CHARACTERISTICS

COMPOUNDS: SO_2, CO, CO_2, NH_3, hydrocarbons

MANUFACTURER: MSA Instrument Division

MODEL: LIRA Luft-Type Infrared Analyzer 303

PERFORMANCE

Reproducibility: $\pm$ 1% of full scale

Noise: <1% of f-ll scale

Lag Time: Response time is 5 seconds (fast response time models available)

Zero Drift: <1% in 24 hrs.

Span Drift: <1% in 24 hrs.

OPERATION

Ambient Temperature Range: 5^{C} to $49^{O}C$ (40^{O} to $120^{O}F$)

REQUIREMENTS

Power: 110 V, 60 Hz, 60 W

Weight: 17 Kg (37 lb)

Dimensions: 21 cm H, 26 cm W, 52 cm D (8-1/4" X 10-1/2" X 20-7/16")

FEATURES

Output: Meter, recorder output 50-100 mV

COST

Model 303 $1,935

COMPOUNDS: CO, CO_2, SO_2, NH_3, NO, NO_2 and hydrocarbons by changing cells

MANUFACTURER: MSA Instrument Division

MODEL: LIRA Luft-Type Infrared Analyzer 202

PERFORMANCE

Accuracy: ± 1% of full scale

Reproducibility: ± 1% of full scale

Linearity: Usually within 5%, always within 10%

Noise: <1% of full scale

Lag time: 24 sec - Response time is 5 seconds (fast response time models available)

Zero Drift: <1%/24 hr, -0.0124 ppm/24 hr

Span Drift: <1%/24 hr, 3.033%/24 hr.

OPERATION

Ambient Temperature Range: -1^{o} to $49^{o}C$ (30^{o} to $120^{o}F$)

REQUIREMENTS

Power: 115 V, 50/60 Hz, 500 W

Weight: 22 Kg (49 lb)

Dimensions: 32 cm H, 48 cm W, 33 cm D (12-1/2" X 19" X 13")

FEATURES

Output: Meter and recorder output terminal 0-10, 0-25, 0-50, 0-100mV

COST

Model 202, Standard Cell Length, gen. pur. $2,855

Model 202X, Standard Cell Length, explosion proof $3,210

Model 202S, with separate sheet metal case for 20" cells, general $3,350

Model 202SX, with separate explosion proof case for 20" cell,
explosion proof $4,415

Model 202FR, Fast Response, general purpose $2,855

COMPOUNDS: SO_2, CO and CO_2

MANUFACTURER: Leeds & Northrup

MODEL: 7864 and 7865 Infrared Analyzers

SAMPLING

Maximum Temperature Input: 93°C (200°F)

PERFORMANCE

Accuracy: ± 1% of span or ± 0.003% of gas (whichever is greater)

Reproducibility: ± 1.5% of span or ± 0.003% of gas (which ever is greater)

Lag Time: 1 sec.

Zero Drift: ± 0.7%/24 hr & ±2%/7 days

Span Drift: ± 0.1%/24 hr & 0.3%/7 days

OPERATION

Ambient Temperature Range: 4° to 49°C (40° to 120°F)

REQUIREMENTS

Power: 108-132 V, 50/60 Hz

Weight: 31.7 Kg (70 lb)

Dimensions: 37 cm W, 108 cm H, 30 cm D (14-5/8" X 42-3/8" X 11-5/8")

FEATURES

Output: 0-10 mV standard, current outputs 0-16 mA, 4-20 mA, 0-20 mA, 0-40 mA, and 10-50 mA.

COMPOUNDS: Several, by change or use of different sensor

MANUFACTURER: RPC

MODEL: Biosensor Vapor Detection System, 1332-16

SAMPLING

Method: Continuous

Volume: 300-600 cc/min

Collection Efficiency: Maximum possible

PERFORMANCE

Accuracy: Not computed

Reproducibility: $\pm$ 20%

Linearity: Not calculated

Noise: 40% of minimum detectable sensitivity

Lag Time: <5 sec for gaseous pollutants

Retention Time: Function of concentration, usually <5 sec

Fall Time: <10 sec for low concentration; <60 sec for crash concentration

Zero Drift: Not determined

Span Drift: Self zeros, time not determined

OPERATION

Ambient Temperature Range: 0^{o} to $32^{o}C$ (32^{o} to $90^{o}F$)

Temperature Compensation: Internal

Relative Humidity Range: 40-90% R.H.

Procedure: Self explained in operation manual

Unattended Period: -0-

Maintenance: Minimal with dust and particulate cleaning performed on a weekly basis

REQUIREMENTS

Power: 110 Vac, 60 H_z; 220 Vac optional

Weight: 4Kg (10 lb)

Dimensions: Control unit 18 cm H, 23 cm W, 18 cm D (7" X 9" X 7")
(Sensing unit and handle 8 cm H, 15 cm W, 11 cm D + 9 cm probe)
(3" X 6" X 4-1/2" + 3-1/2" probe)

FEATURES

Output: Meters, lights, audible alarm and recorder output

Training: in-house or in-field

COST

Model 1332-16 $6,830

COMPOUNDS: SO_2, NO, CO, CO_2, and total hydrocarbons

MANUFACTURER: Infrared Industries

MODEL: Series 700

SAMPLING

Method: Continuous-pump

Volume: 1 CFH

Maximum Temperature Input: Below due point

PERFORMANCE

Accuracy: 1% of full scale

Reproducibility: 0.5% of full scale

Linearity: $\pm$ 1% of full scale

Noise: < 1% of full scale

Fall Time: <5 sec.

Zero Drift: <5%/24 hr, <1%/1 hr

Span Drift: <5%/24 hr, <1%/1 hr

OPERATION

Ambient Temperature Range: 0^{o} to $49^{o}C$ (32^{o} to $120^{o}F$)

Temperature Compensation: None required (due to automatic gain control)

Relative Humidity Range: 0-99%

REQUIREMENTS

Power: 115 V, 60 Hz, 50 W

Weight: 11 Kg (25 lb)

Dimensions: 23cm H, 43cm W, 43cm D (9" X 17" X 17")

FEATURES

Output: 0-100 mV

COST

Series 700	$1500

COMPOUNDS: SO_2, NO, CO, CO_2, opacity

MANUFACTURER: Environmental Data Corporation

MODEL: Diga-Series In-Situ Emission Monitors

SAMPLING

Method: Continuous - measures inside the stack, no sampling system required

Maximum Temperature Input: As required - no limit

Collection Efficiency: Integrated analysis across stack or duct

PERFORMANCE

Accuracy $\pm$ 2%

Reproducibility: $\pm$ 1%

Noise: typically $\leq$2%

Lag Time: Instantaneous - no sample system

Zero Drift: <2% in 30 days

Span Drift: <2% in 30 days

OPERATION

Ambient Temperature Range: As required

Unattended Period: 30 days

Maintenance: Factory provides installation engineering, start-up, calibration, and maintenance

REQUIREMENTS

Power: 115 V, 60 Hz

FEATURES

Output: millivolt, volt, milliamp

COMPOUNDS: SO_2, NO_2, NO_x, CO, CH_2O by replacing sensor

MANUFACTURER: Dynasciences Corporation

MODEL: Carbon Monoxide Monitor Model CO-530

SAMPLING

Method: Continuous-pump in optional Sampling unit

Volume: 0.24 to 1.0 liters/min (0.5 to 2.0 CFH)

Maximum Temperature Output: 43°C (110°F)

Collection Efficiency: Not applicable

PERFORMANCE

Accuracy: $\pm$ 2% of full scale

Reproducibility: $\pm$ 2%

Linearity: < 1/2% over entire range

Noise: $\leq$ 0.1% rms of full scale

Lag Time: 0.1 sec

Retention Time: 0.1 sec

Zero Drift: 1% in 24 hr

Span Drift: 1% in 24 hr

OPERATION

Ambient Temperature Range: 4° to 43°C (40° to 110°F)

Temperature Compensation: Compensated to $\pm$ 10% between 4° to 43°C (40° to 110°F) for optimum accuracy, temperature control units are recommended.

Relative Humidity Range: 0- 99% at 37.8°C (100°F)

Unattended Period: 1 week minimum

Maintenance: Weekly zero and span checks are recommended

REQUIREMENTS

Power: 115/230 V, 50/60 H_z, option 12 Vdc

Weight: 5.9 Kg (13 lb)

Dimensions: 21 cm H, 28 cm W, 28 cm D 8.25" X 11" X 11")

FEATURES

Output: meter, 0-10 mV recorder connection

Training: not required

COST

Monitor Model CO-530	$2,395
Sampling Unit Model CXS-1000	1,680

COMPOUNDS: CO

MANUFACTURER: Devco Engineering Inc.

MODEL: Series 10 APM Environmental Co.

SAMPLING

Method: Continuous (Sample is drawn through a series of filters & scrubbers to remove particulates & hydrocarbons)

PERFORMANCE

Accuracy: $\pm$ 0.5%

Reproducibility: $\pm$ 1% of full scale

Linearity: 1.0% of full scale

Noise: $\pm$ 0.5%

Lag Time: Approximately 15 sec

Zero Drift: <1%/week

Span Drift: <1%/week

OPERATION

Ambient Temperature Range: 7^{o} to 35^{o} (45^{o} to 95^{o}F) limited by recorder

Temperature Compensation: Solid state proportional temperature controller

Relative Humidity Range: 10 to 100%

Unattended Period: At least two weeks

Maintenance: Catalyst life 18-24 months

FEATURES

Output: Meter

COMPOUNDS: CO, CO_2, CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_4H_{10}, C_6H_{14}, NH_3, N_2O, NO. et al., dependent on filter

MANUFACTURER: Bendix Corporation

MODEL: Infrared Gas Analyzer UNOR 2

SAMPLING

Method: Continuous-pump or external pressure

Volume: 0.47 liters/min

Maximum Temperature Input: 35°C

Collection Efficiency: 100%

PERFORMANCE

Accuracy: ± 1% of full scale

Reproducibility: ± 1% of full scale

Lag Time: 2 sec

Zero Drift: ± 1% of full scale

Span Drift: ± 1% of full scale

OPERATION

Ambient Temperature Range: 15 to 35°C

Temperature Compensation: Achieved by a temperature dependent feedback to amplifier

Relative Humidity Range: To 98%

Procedure: Assembly is gasketed and can be air purged & interlocked.

Maintenance: Supply reference gas N_2 (sealed or flowing)

REQUIREMENTS

Power: 110 V, 60 Hz, 20 W

Weight: 22 Kg (49 lb)

Dimensions: 51 cm H, 37 cm W, 15 cm D (20" X 14-1/2" X 6")

FEATURES

Output: Meter, recorder connection 0.1-1.0 mA (live zero output)

COST

UNOR 2 with one range	$3,403
UNOR 2 with dual ranges	$3,685

COMPOUNDS: CO, CH_4 and total hydrocarbons

MANUFACTURER: Bendix Corporation

MODEL: Series 8200 Environmental Chromatograph

SAMPLING

Method: Continuous (cyclic operation)-pump

Volume: 200 cc per min.

Collection Efficiency: 100%

PERFORMANCE

Accuracy: $\pm$ 1% of full scale

Reproducibility: $\pm$ 1% of full scale

Linearity: $\pm$ 0.5%

Noise: < 0.01 ppm

Lag Time: Does not apply. 5 min cycle time.

Retention Time: Does not apply. 5 min cycle time.

Fall Time: Does not apply. 5 min cycle time.

Zero Drift: $\pm$ 1% for 24 hr. or $\pm$ 2% for 3 days

Span Drift: $\pm$ 1% for 24 hr or $\pm$ 2% for 3 days

OPERATION

Ambient Temperature Range: 5^{o} to $40^{o}C$

Temperature Compensation: Limit ambient fluctuation to $\pm$ $5^{o}C$. Sample loops, injection valves and columns are controlled to $\pm$ $0.5^{o}C$.

Relative Humidity Range: to 95%

Procedure: With gas of known concentration

Unattended Period: 7 days

Maintenance: Provide gases for operation.

Periodic replacement of sample particulate filter.

REQUIREMENTS

Power: 115 ± 10 V, 50 or 60 Hz as specified 500 W, 700 VA Max.

Weight: approximately 115 Kg (250 lb)

Dimensions: 107 cm H, 56 cm W, 58 cm D (41" X 22" X 23")

FEATURES

Output: Meter, recorder connections)-1DmV + 0-1 V Dc

Training: Factory training course

COST

Series 8200 Environmental Chromatograph	$6,900

Procedure: Chart supplied with instrument which gives a specific instrument reading when inserted instead of tape cassette.

Unattended Period: 168 hours (1 week of 24 hour operation)

Maintenance: None required except to change cassette once per week

REQUIREMENTS

Power: 115 V, 60 Hz, 35 W

Weight: 10 Kg (22 lb)

Dimensions: 24 cm H, 41 cm W, 25 cm D (9-1/4" X 16" X 10")

FEATURES

Recorder Output: 0-1 mA dc or 0-100 mV dc

Training: None

COST

Model 7050 $2,465

COMPOUNDS: The Model 7050 can be modified to also measure H_2S, NO_2, Phosgene, Chlorine, Amonia and T D I.

MANUFACTURER: Universal Environmental Instruments (U.K.) Ltd.

MODEL: Model 7050 CO Detector

SAMPLING

Method: Continuous, with self-contained pump, needle valve & flow meter

Volume: 500 cc/min

Collection Efficiency: 100%

PERFORMANCE

Accuracy: $\pm$ 10% of reading

Reproducibility: Better than 5%

Linearity: Better than 5%

Noise: 1.0%

Lag Time: 30 seconds

Retention Time: 30 seconds

Fall Time: 30 seconds

Zero Drift: Better than 1% for 24 hours

Span Drift: Better than 1% for 24 hours

OPERATION

Ambient Temperature Range: 0 to 40°C

Temperature Compensation: None

Relative Humidity Range: 0-100% RH

COMPOUNDS: CO

MANUFACTURER: MSA Instrument Division

MODEL: Portable CO Indicator Model D

SAMPLING

Method: Continuous-pump

Volume: Approximately 1.5 liters/min.

PERFORMANCE

Accuracy: ± 1% of full scale

Reproducibility: ± 5%

Lag Time: Response time -50 sec (90% of value) with 5 ft sample line

Zero Drift: ± 1%/10 min

REQUIREMENTS

Power: Battery powered - 72 volts

Weight: 3 Kg (7-1/2 lbs)

COST

Model D $367.50

Battery Charger $42.00

Alarm Unit $210.00

COMPOUNDS: CO

MANUFACTURER: Matheson Gas Products

MODEL: Carbon Monoxide Detector Models 8031, 8032, 8033

PERFORMANCE

Accuracy: $\leq \pm$ 1% of full scale

COST

Model 8031	$1545
Model 8032	$1545
Model 8033	$1545

COMPOUNDS: NO

MANUFACTURER: Enraf-Nonius

MODEL: TNO Ambient Monitor NO

SAMPLING

Method: Continuous

Volume: 2.4 liter/hour

Collection Efficiency: Better than 95%

PERFORMANCE

Linearity: Better than 2% of full scale

Lag Time: Integrated NO concentration is measured over periods of a 1/2 hour.

Retention Time: Integrated NO concentration is measured over periods of a 1/2 hr.

Fall Time: Integrated NO concentration is measured over periods of a 1/2 hr.

Zero Drift: Compensation provided for

Span Drift: < 5% in 3 months

OPERATION

Ambient Temperature Range: 0^{o} to $30^{o}C$

Relative Humidity Range: 10 to 100%

Procedure: Reagent consumption is 10 liters per 3 months

Unattended Period: 3 months

Maintenence: Twice per annum

REQUIREMENTS

Power 115 V, 60 Hz; 220 V, 50 Hz; 150 W

Weight: 30kg (measuring unit)

7 Kg (reagent storage container)

Dimensions: 45 cm H, 52 cm W, 40 cm D (measuring unit)

45 cm H, 24 cm W, 40 cm D (reagent storage container)

FEATURE

Output: 0-100 mV

COMPOUNDS: SO_2 and NO_2 in the same unit, NO_x, CO, and CH_2O by replacing sensor

MANUFACTURER: Dynasciences Corporation

MODEL: Multi-Pollutant Gas Analyzer NS 410

SAMPLING

Method: Continuous-sampling capability within unit

Volume: 0.24 to 1.0 liters/min (0.5 to 2.0 CFH)

PERFORMANCE

Accuracy: $\pm$ 2%

Reproducibility: $\pm$ 0.5% minimum

Linearity: $\pm$ 1/2 % over entire range

Noise: $\leq$0.1 rms of full scale

Lag Time: 0.2 sec

Retention Time: 0.2 sec

Fall Time: <5 min

Zero Drift: $\pm$ 2%/24 hr

Span Drift: $\pm$ 2/24 hr

OPERATION

Ambient Temperature Range: 4.4^{o} to 43^{o}C (40^{o} to 110^{o}F)

Temperature Compensation: $\pm$ 10% (40^{o} to 110^{o}F)

Relative Humidity Range: 0 - 99% at 37.8^{o}C (100^{o}F)

Unattended Period: up to 30 days

Maintenance: Weekly zero and span checks are recommended.

REQUIREMENTS

Power: 115/230 V, 50/60 Hz

Weight: 27 Kg (60 lb)

Dimensions: 28 cm H, 49 SL W, 54 cm D (11' X 19-1/2" X 21-1/2")

FEATURES

Output: meter, two recorder outputs 0-1 Vdc

Training: Not required

COST

Model NS 410	$6,450

COMPOUNDS: SO_2, NO_2, NO_x, CO, CH_2O by replacing sensor

MANUFACTURER: Dynasciences Corporation

MODEL: Nitrogen Dioxide Monitor NR-230

SAMPLING

Method: Continuous-pump in optional sampling unit

Volume: 0.24 to 1.0 liters/min (0.5 to 2.0 CFH)

Maximum Temperature Input: 43°C (110°F)

PERFORMANCE

Accuracy: ± 2% of full scale

Reproducibility: ± 2%

Linearity: <1/2 % over entrie range

Noise: ≤0.1% rms of full scale

Lag Time: 0.1 sec

Retention Time: 0.1 sec

Fall Time: 6 min

Zero Drift: 1% in 24 hr.

Span Drift: 1% in 24 hr.

OPERATION

Ambient Temperature Range: 4° - 43°C (40° to 110°F)

Temperature Compensation: Compensated to ± 10% between 4° to 43°C (40° to 110°F). For optimum accuracy, temperature controlled units are recommended.

Relative Humidity Range: 0 - 99% at 37.8°C (100°F)

Unattended Period: 1 week minimum

Maintenance: Weekly zero and span checks are recommended

Requirements

Power; 115/230 V, 50/60 Hz, option 12 Vdc

Weight: 5.9 Kg (13 lb)

Dimensions: 21 cm H, 28 cm W, 28 cm D (8.25" X 11" X 11")

FEATURES

Output: Meter, 0-10 mV recorder connection

Training: Not required

COST

Monitor Model NR-230	$2,000
Sampling Unit Model CXS-1000	$1,680

COMPOUNDS: NO_x/SO_2, NO_x/NO_2 or NO_2/SO_2

MANUFACTURER: Dynasciences Corporation

MODEL: Single Gas Analyzer Models P100R & P100D

Dual Gas Analyzer Models P101R & P101D

SAMPLING

Method: Continuous-unit includes all necessary equipment to sample, condition and monitor source gases. Sampling acquisitioning is accomplished through the use of a sintered stainless steel filter capable of removing 98% of the particles above 0.7 microns & 100% of those above 1.8 microns. Heated sample lines are available.

PERFORMANCE

Reproducibility: $\pm$ 1% minimum

Linearity: $\pm$ 1/2% within any range

Lag Time: Response time NO_x -30 sec
NO_2 -8 min

Zero Drift: $\leq\pm$ 2% / 24 hr.

Span Drift: $\leq\pm$ 2%/ 24 hr.

OPERATION

Ambient Temperature Range: 4^o to 43^oC (40^o to 110^oF)

Temperature Compensation: Temperature controlled at 43^oC (110^oF)

REQUIREMENTS

Power: 115 V, 50/60 Hz 1100 W maximum

Weight: 39 Kg (85 lb)

FEATURES

COST

Model P100R	$4,950
Model P100D	$6,400
Model P101R	$6,450
Model P101D	$7,950

COMPOUNDS: PM 123 - NO_2 and NO

PM 124 - NO_2 and SO_2

MANUFACTURER: CEA Instruments

MODEL: PM 123 and PM 124 sensors

SAMPLING

Method: Continuous

Volume: 250 to 500 ml/min

Collection Efficiency: 96%

PERFORMANCE

Accuracy: 2%

Reproducibility: 1%

Lag Time: 3 min.

Zero Drift: 2% in one week

Span Drift: 2% in one week

OPERATION

Ambient Temperature Range: 2^{o} to $43^{o}C$ (36^{o} to $110^{o}F$)

Temperature Compensation: None

Relative Humidity Range: 0-100%

Unattended Period: 2 weeks

Maintenance: Reagent change every 2 weeks; pump tube change every month; general cleaning and calibration every 6 months

REQUIREMENTS

Power: 12 Vdc (120 V, 60 Hz with AC pack)

Weight: 7 Kg (16 lb)

Dimensions: 46 cm W, 31 cm H, 25 cm D (18" X 12" X 10")

FEATURES

Output: 0-100 mV or 0-10 μA; no built-in recorder

Training: None required

COST

PM 123 or PM 124 with DC power pack	$2,690
PM 123 or PM 124 with AC power pack	$2,970

COMPOUNDS: Modification to SO_2 or NO_2

MANUFACTURER: CEA Instruments

MODEL: PM 113 NO_x Sensor

SAMPLING

Method: Continuous

Volume: 250 to 500 ml/min

Collection Efficiency: 96%

PERFORMANCE

Accuracy: 2%

Reproducibility: 1%

Lag Time: 3 min.

Zero Drift: 2% in one week

Span Drift: 2% in one week

OPERATION

Ambient Temperature Range: 2^{o} to $43^{o}C$

Temperature Compensation: None

Relative Humidity Range: 0-100%

Procedure: Controls are provided to initiate a purge/calibrate cycle either manually or automatically.

Unattended Period: 2 weeks

Maintenance: Reagent change every 2 weeks; pump tube change every month; general cleaning and calibration every 6 months.

REQUIREMENTS

Power: 110 V, 60 Hz, 110 W

Weight: 8 Kg (18 lb)

Dimensions: 30.5 cm W, 20.5 cm H, 25.4 cm D (12" X 12" X 10")

FEATURES

Output: 0-100 mV or 0-10 A; no built in recorder

COST

PM 113 $2,150

COMPOUNDS: SO_2, NO_2, NO_x, CO, CH_2O by replacing sensor

MANUFACTURER: Dynasciences Corporation

MODEL: Oxides of Nitrogen Monitor, NS-130

SAMPLING

Method: Continuous-pump in optional sampling unit

Volume: 0.24 to 1.0 liters/min (0.5 to 2.0 DFH)

Maximum Temperature Input: 43°C (110°F)

PERFORMANCE

Accuracy: $\pm$ 2% of full scale

Reproducibility: $\pm$ 2% , 1%

Linearity: <1/2% over entire range

Noise: $\leq$ 0.1% rms of full scale

Lag Time: 0.1 sec , 7.8 sec (includes SO_2 scrubber)

Fall Time: 20 sec.

Zero Drift: 1% in 24 hours

Span Drift: 1% in 24 hours

OPERATION

Ambient Temperature Range: 4° to 43°C (40° to 110°F)

Temperature Compensation: Compensated to $\pm$10% between 4° to 43°C (40° to 110°F) - For optimum accuracy, temperature controlled units are recommended.

Relative Humidity Range: 0 - 99% at 37.8°C (100°F)

Unattended Period: 1 week minimum

Maintenance: Weekly zero and span checks are recommended

REQUIREMENTS

Power: 115/230 V, 50/60 Hz, option 12 Vdc

Weight: 5.9 Kg (13 lb)

Dimensions: 21 cm H, 28 cm W, 28 cm D (8.25" X 11" X 11")

FEATURES

Output: Meter, 0-10 mV recorder connection

Training: Not required

COST

Monitor Model NX-130 $2,000

Sampling Unit Model CXS-1000 $1,680

COMPOUNDS: CO, CO_2, CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_4H_{10}, C_6H_{14}, NH_3, N_2O, NO, et al., dependent on filter

MANUFACTURER: Bendix Corporation

MODEL: Infrared Gas Analyzer UNOR 2

SAMPLING

Method: Continuous-pump or external pressure

Volume: 0.47 liters/min

Maximum Temperature Input: 35°C

Collection Efficiency: 100%

PERFORMANCE:

Accuracy: ± 1% of full scale

Reproducibility: ± 1% of full scale b, <1% d

Lag Time: 2 sec b, 11.7 sec d

Zero Drift: ± 1% of full scale

Span Drift: ± 1% of full scale

OPERATION

Ambient Temperature Range: 15 to 35°C

Temperature Compensation: Achieved by a temperature dependent feedback to amplifier

Relative Humidity Range: to 98%

Procedure: Assembly is gasketed and can be air purged and interlocked.

Maintenance: Supply reference gas N_2 (sealed or flowing)

REQUIREMENTS

Power: 110 V, 60 Hz, 20 W

Weight: 22 Kg (49 lb)

Dimensions: 51 cm H, 37 cm W, 15 cm D (20" X 14-1/2" X 6")

FEATURES

Output: Meter, recorder connection 0.1-1.0 mA (live zero output)

COMPOUNDS: CO, N_2O, NO, NO_2, CH_4, C_2H_2, SO_2 and most other heteroatomic gases except H_2O & CO_2

MANUFACTURER: Calibrated Instruments Inc.

MODEL: Infrared Gas Analyzer SC/LC

SAMPLING

Method: Continuous-pump

Volume: 2 liters/min

PERFORMANCE:

Accuracy: $\pm$ 2% of full scale

Reproducibility: < 1% of full scale

Lag Time: 0.1 sec

Zero Drift: $\pm$ 0.9%

Span Drift: 1.0%

OPERATION

Ambient Temperature Range: 0^{o} to $40^{o}C$ (32^{o} to $104^{o}F$)

Temperature Compensation: 1% per ^{o}C if without thermostat control

Relative Humidity Range: to $82^{o}C$ ($107.6^{o}F$)

Maintenance: Replace detector cell after 24 months or longer

REQUIREMENTS

Power: 95-130 V, 60 Hz; 190-260 V, 50 Hz; 50 VA; 100 VA with sampling pump

Weight: 25 Kg (56 lb)

Dimensions: 52 cm H, 46 cm W, 27 cm D (20.5" X 18" X 10.5")

FEATURES

Output: Meter, chart recorder connection

COST

Infrared Gas Analyzer SC/LC $2,995

COMPOUNDS: NO_x with external converter

MANUFACTURER: Bendix Corporation

MODEL: 8102 NO - NO_x Analyzer

SAMPLING

Method: Continuous

Volume: 20 to 30 cc/min and 150 cc/min oxygen

Maximum Terperature Input: 150° to 200°C

Collection Efficiency: 100°

PERFORMANCE

Accuracy: ± 1% of full scale

Reproducibility: ± 1%

Linearity: ± 0.5% full scale

Noise: 0.5 ppm

Lag Time: 5 seconds

Retention Time: 5 seconds

Fall Time: 15 seconds

Zero Drift: ± 2% for 24 hours

Span Drift: ± 2% for 24 hours

OPERATION

Ambient Temperature Range: 5° to 40°C

Temperature Compensation: Limit ambient fluctuations to ± 5°C. Photomultiplier tube and reaction chamber with analytical components temperature controlled.

Relative Humidity Range: to 95%

Procedure: With Gas of known concentration

Unattended Period: 7 days

Maintenance: Provide oxygen for operation. Periodic replacement of sample particulate filter and exhaust gas activated charcoal scrubber.

REQUIREMENTS

Power: 115 ± V, 50 or 60 Hz as specified, 350 W

Weight: Approximately 27 Kg (60 lb)

Dimensions: 42 cm W, 22 cm H, 46 cm D (8-1/2" X 16-1/2" X 18")

FEATURES

Output: 0-10 mV and 0-1 Vdc

Training: Factory training course

COST

Model 8102 (for NO only) $4,250

with converter option $4,675

COMPOUNDS: Model A100 - NO_2

Model A1001 - $NO/NO_2/NO_x$

MANUFACTURER: Freeman Laboratories, Inc.

MODEL: $NO_2/NO/NO_x$ Continuous Analyzer Models A100 and A1001

SAMPLING

Method: Continuous

Collection Efficiency: 99 + %

PERFORMANCE

Lag Time: 6-15 sec

Zero Drift: maximum 1%/day

Span Drift: maximum 1%/day

REQUIREMENTS

Power: 115 V/60 Hz/0.25 amps or 220 V/50 Hz/0.125 amps

Weight: 18 Kg (40 lb)

Dimensions: 30 cm H, 28 cm W, 37 cm D (12" X 11" X 14-1/2")

FEATURES

Output: Recorder

COST

Model A100 (NO_2) Standard	$3,400
Self calibrating	$4,500
Model A1001 ($NO/NO_2/NO_x$) standard	$4,150
Self calibrating	$5,250

COMPOUNDS:

MANUFACTURER: Bendix Corporation

MODEL: 400 Gas Detector

SAMPLING

Method: Intermittent - manual pump

Volume: 1-100 ml

PERFORMANCE

OPERATION

Procedure: Gas to be sampled is drawn through detector tube and length of stain compared to concentration chart provided.

Maintenance: Tube replacement

REQUIREMENTS

FEATURES

Output: Length of stain

COST

Model 400 $90.00

COMPOUNDS: NO, NO_x with NO_2 derived from the NO_x - NO difference

MANUFACTURER: Bendix Corporation

MODEL: 8101B

SAMPLING

Method: Continuous

Volume: 150 cc/min sample and 30 cc/min oxygen

PERFORMANCE

Accuracy: $\pm$ 0.01 ppm or $\pm$ 2% whichever is greater on the 0 to 2.0 ppm scale

Reproducibility: $\pm$ 0.01 ppm from .005 to 2.0 ppm measured at integrator output

Linearity: $\pm$ 0.5% full scale

Noise: $\pm$ 0.5 % of full scale

Lag Time: 5 sec

Retention time: 5 sec on NO mode

Fall time: Less than 15 sec on NO mode

Zero Drift: Less than 0.01 ppm in 24 hr. on the 2.0 ppm range and less than 0.05 ppm for 3 days on the 2.0 ppm range

Span Drift: Less than 0.08 ppm in 24 hr. on the 2.0 ppm range and less than 0.08 ppm for 3 days on the 2.0 ppm range

OPERATION

Ambient Temperature Range: 5^{o} - $40^{o}C$

Temperature compensation: Limit ambient fluctuations to $\pm$ $5^{o}C$. Photomultiplier tube and reaction chamber temperature control

Relative Humidity Range: to 95%

Procedure: With gas of known concentration

Unattended Period: 7 days

Maintenance: Provide gases for operation. Periodic replacement of sample particulate filter and exhaust gas activated charcoal scrubber.

REQUIREMENTS

Power: 115 $\pm$ 10 V, 50 or 60 H_z as specified, 350 W

Weight: approximately 27 Kg (60 lb)

Dimensions: 22 cm H, 42 cm W, 43 cm D (8-1/2" X 16-1/2" X 17")

FEATURES

Output: Meter, recorder 0-10 mV and 0-1 Vdc

Training for Operation: Factory training course

COST

Model 8101B $5,870

REQUIREMENTS

Power: 115 ±10 V, 50 or 60 Hz as specified, 500 W, 700 VA max

Weight: Approximately 115 Kg (250 lbs)

Dimensions: 107 cm H, 56 cm W, 58 cm D (41" x 22" x 23")

FEATURES

Input: Meter, recorder connections 0-10 mV and 0-1 V dc

Training: Factory training course

COST

Series 8200 Environmental Chromatograph	$6900

COMPOUND: Hydrocarbons

MANUFACTURER: Teledyne

MODEL: Series 400

SAMPLING

Method: Continuous

Volume: 100 ml to 400 ml per minute of sample

Maximum Temperature Input: 177°C (350°F)

Collection Efficiency: 100%

PERFORMANCE

Accuracy: 1% of full scale range

Reproducibility: ±1%

Linearity: ±2%

Noise: < ±1/2% full scale

Lag Time: 15 seconds

Retention Time: 15 seconds

Fall Time: 1 second

Zero Drift: less than 1%

Span Drift: less than 1%

OPERATION

Ambient Temperature Range: 4° to 38°C (40° to 100°F)

Temperature Compensation: Contains proportional temperature controller

Unattended Period: 1 day

COMPOUNDS: CO, CO_2, hydrocarbons, nitrogen and sulfur compounds

MANAFACTURER: Varian Aerograph

MODEL: 2732

SAMPLING

Method: Cyclic-gas sampling valve

Volume: Variable

Maximum Temperature Input: 225°C

PERFORMANCE

Accuracy ±1%

Reproducibility: ±1%

Noise: < 5 microvolts

Retention Time: Variable

Zero Drift: < 10 microvolts/month

OPERATION

Maintenance: Monthly-minimal

REQUIREMENTS

Power: 115 V, 20 amp

Weight: 341 Kg (155 lb)

Dimensions: 51 cm H, 49 cm W, 55 cm D (20 1/4" x 19 3/8" x 21 3/4")

FEATURES

Output: Recorder

Training: Optional at extra cost

COST

Model 2732 $5195 to 7,395

REQUIREMENTS

Power: 115 V, 60 Hz, 200 watts (Model 403), 350 watts (Model 404)

Weight: Approximately 18 Kg (40 lb)

Dimensions: Model 403: 46 cm H x 56 cm W x 46 cm D (18" x 22" x 18")

Model 404: 51 cm H x 56 cm W x 46 cm D (20" x 22" x 18")

FEATURES

Output: Meter, provision for 0-5 mV dc recorder

Training: Available from manufacturer

COST

Model 403 (for sampling systems with dew points below 52°C [125°F]) $2750

Model 404 (for sampling systems with dew points up to 66°C [175°F]) $7500

COMPOUNDS: Total hydrocarbons based on methane equivalent

MANAFACTURER: Wemco Instrumentation Company

MODEL: Automatic Gas Detector and Alarm System Model MUC 12CS

SAMPLING

Method: Continuous-positive vaccum pressure

Volume: Approximately 70 SCFH air

Maximum Temperature Input: 49°C (120°F)

Collection Efficiency: 100% at sample input point at time of reading

PERFORMANCE

Accuracy: ±3% of full scale

Reproducibility: ±3% of full scale

Linearity: ±3% of full scale

Noise: Negligible

Lag Time: 10 seconds through one 200 foot 1/4" tube

Retention Time: 3 seconds through one 200 foot 1/4" tube

Fall Time: 2 seconds

Zero Drift: Negligible

Span Drift: Negligible

OPERATION

Ambient Temperature Range: 18° to 35°C (65° to 95°F)

Relative Humidity Range: 0 to 100%

Unattended Period: unknown

Maintenance: Approximately 2 hours per year plus cylinder changing

REQUIREMENTS

Power: 120 V. 60 Hz or 240 V, 50 Hz

Weight: Approximately 77 Kg (170 lbs)

Dimensions: 155 cm H, 57 cm W, 65 cm D (61" x 22 1/2" x 25 1/2")

FEATURE

Output: 0-1ma dc meter relay readout

Training: Available at nominal charges

COST

Model MUC 12CS	$3,950
(explosion proof model)	$4,975

COMPOUNDS: NO, CO, CO_2 and Hydrocarbons

MANUFACTURER: Horiba Instruments Incorporated

MODEL: Modular Non-Dispersive Infrared Gas Analyzer Model AIA-21

SAMPLING

Method: Continuous

Volume: 2 to 20 CFH

Maximum Temperature Input: 40°C (105°F)

PERFORMANCE

Accuracy: ±1%

Reproducibility: ±1%

Linearity: 5% of full scale at mid-scale (linearizer available)

Noise: < 1%

Lag Time: Response time -0.5 seconds

Zero Drift: 1% of full scale/8 hours

Span Drift: 1% of full scale/8 hours

OPERATION

Ambient Temperature Range: 0° to 40°C (32° to 105°F)

Temperature Compensation: Thermostatically controlled

Relative Humidity Range: 0-90% RH at 20°C (68°F)

REQUIREMENTS

Power: 115 V, 60 Hz or 230 V, 50 Hz, 250 W

Weight: Analyzer Section - 10 Kg (21 lbs)

Amplifier Section - 7 Kg (16 lbs)

Dimensions: Analyzer Section - 46 cm H, 10 cm W, 16 cm D

(200 mm cell) (18" x 4" x 6-1/10")

Amplifer Section - 15 cm H, 24 cm W, 46 cm D
(6" x 9-3/8" x 18")

FEATURES

Output: 0-10 V and 0-100 mV dc for recorder and 0-1 V and 0-5 V input to Data Acquisition System

COMPOUNDS: Total hydrocarbons, CH_4 and CO

MANUFACTURER: Hewlett-Packard Company

MODEL: 5781 A Environmental Analyzer

REQUIREMENTS

Weight: 43 Kg (95 lbs)

Dimensions: 35 cm H, 68 cm W, 48 cm D (13 1/2" x 27" x 19");
including detector: 47 cm H (18 1/2")

COST

Model 5781A	$3,985
opt. 34 (Total hydrocarbon analysis capability)	$1,140

COMPOUNDS: SO_2, CO, CO_2, NH_3, hydrocarbons

MANUFACTURER: MSA Instrument

MODEL: 303

PERFORMANCE

Reproducibility:	±1% of full scale
Noise:	< 1% of full scale
Lag Time:	Response time is 5 seconds (fast response time models available)
Zero Drift:	< 1% in 24 hours
Span Drift:	< 1% in 24 hours

OPERATION

Ambient Temperature Range: 5° to 49°C (40° to 120°F)

REQUIREMENTS

Power: 110 V, 0 Hz, 60 W

Weight: 17 Kg (37 lbs)

Dimensions: 21 cm H, 26 cm W, 52 cm D (8-1/4" x 10 1/2" x 20-7/16")

FEATURES

Output: Meter, recorder output 50-100 mV

COST

Model 303 $1,935

COMPOUNDS: Total hydrocarbons only

MANAFACTURER: MSA Instrument Division

MODEL: Total hydrocarbon Analyzer MSA 2

SAMPLING

Method: Continuous

PERFORMANCE

Accuracy: 1%

Linearity: Linear over operative ranges

Noise: $<\pm 1$ of full scale

Zero Drift: <1%/24 hours

Span Drift: <1%/24 hours

REQUIREMENTS

Power: 115 V, 60 Hz

Weight: 16 Kg (35 lbs)

Dimensions: 32 cm H, 48 cm W, 33 cm D (12 1/2" x 19" x 13")

FEATURES

Output: 0-5, 0-10, 0-50 mv

COST

Total Hydrocarbon Analyzer $2,023

COMPOUNDS: Methane, total hydrocarbons and total hydrocarbons less methane only

MANUFACTURER: MSA Instrument Division

MODEL: 11-2

SAMPLING

Method: Continuous

PERFORMANCE

Accuracy: 1% of full scale

Reproducibility: 1% of full scale

Linearity: Linear over range

Noise: < ±1% of full scale

Lag Time: Response time is 15 seconds, 100% of reading

Zero Drift: <1%/24 hours

Span Drift: <1%/24 hours

OPERATION

Ambient Temperature Range: 5^{o} to $49^{o}C$ (40^{o} to $110^{o}F$)

REQUIREMENTS

Power: 115 V, 60 Hz, 1,000 Watts

Weight: 27 Kg (60 lbs)

Dimensions: 84 cm H, 51 cm W, 33 cm D (33" x 20" x 13")

FEATURES

Output: 0-100 mv, 0-1 v, 0-5 v, 0-10 v, 0-1 mv, 1-5 mv, 4-20 mv, 10-50 mv

COST

Model 11-2 Approximately $5,500

APPENDIX C-1
LIST OF ENGINE MANUFACTURERS/ENGINES

The following list includes the names and addresses of the small engine manufacturers contacted for information. Information sought included size (hp), type (# strokes), application (lawn, etc.), emission data, fuel-air mixture, life expectancy and duty cycle. Responses were generally poor.

The list also contains the size range (hp) of the engines produced by each manufacturer.

NAME	ADDRESS	ENGINE SIZES(HP)
1. Briggs & Stratton Corporation	3300 N. 124th Street Wauwatosa, WI 53201	2-16 hp
2. Chrysler Corp.	Marine & Ind. Products Plant Marysville, MI	3-1/4-8hp
3. Clinton Engines Corporation	Maguoketa, IO 52060	4-7hp
4. Homelite (Div. of Textron	70 Riverdale Avenue Port Chester, NY 10573	2- 4hp
5. Jacobsen Mfg. Co.	1721 Packard Avenue Racine, WI 53403	3hp
6. Outboard Marine Corp. (Lawnboy)	Gale Products Division 100 Sea Horse Drive Waukegan, IL 60085	10hp
7. McCulloch Corp.	6101 Century Boulevard Los Angeles, CA 90045	20hp
8. O & R Engines, Inc.	3340 Emery Street Los Angeles, CA 90043	1-2 1/4hp
9. Tecumseh Prod. Co.	Ottawa & Patterson Streets	2-1/2--16hp

1-1/8--3-9/16 bore size single cylinder engines
2500 to 7200 rpm speed range
300 to 500 MM $ industry
12.5 + MM engines/year
Average engine use 50 hrs./year